AFRL-ML-WP-TR-1998-4131

AIR FORCE/INDUSTRY MANUFACTURING COST REDUCTION STUDY

Dr. A. M. Lovelace

MATERIALS AND MANUFACTURING DIRECTORATE
AIR FORCE RESEARCH LABORATORY
AIR FORCE MATERIEL COMMAND
WRIGHT-PATTERSON AFB, OH 45433-7817

JUNE 1998

FINAL REPORT FOR 28 AUGUST 1972 – 1 SEPTEMBER 1972

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

Materials & Manufacturing Directorate
Air Force Research Laboratory
Air Force Materiel Command
Wright-Patterson Air Force Base, OH 45433-7734

NOTICE

THIS TECHNICAL REPORT HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION.

Daniel B. Miracle

DANIEL B. MIRACLE, Project Engineer
Metals Development & Materials
Processing Branch
Metals, Ceramics & NDE Division

Katherine A. Stevens

KATHERINE A. STEVENS, Chief
Metals Development & Materials
Processing Branch
Metals, Ceramics & NDE Division

Norman M. Geyer

NORMAN M. GEYER, Actg Asst Chief
Metals, Ceramics & NDE Division
Materials & Manufacturing Directorate

REPORT DOCUMENTATION PAGE

FORM APPROVED
OMB NO. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302 and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
23 Jun 98

3. REPORT TYPE AND DATES COVERED
Final 28 Aug 1972 - 1 Sep 1972

4. TITLE AND SUBTITLE
AIR FORCE/INDUSTRY MANUFACTURING COST REDUCTION STUDY

5. FUNDING NUMBERS
PR: 2306
TA: AW
WU 2P

6. AUTHOR(S)
Dr. A. M. Lovelace

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(ES)
Materials & Manufacturing Directorate
Air Force Research Laboratory
Air Force Materiel Command
Wright-Patterson Air Force Base, OH 45433-7817

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAMES(ES) AND ADDRESS(ES)
Materials & Manufacturing Directorate
Air Force Research Laboratory
Air Force Materiel Command
Wright-Patterson Air Force Base, OH 45433-7734
POC: Daniel B. Miracle, AFRL/MLLM, 937-255-9833

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
AFRL-ML-WP-TR-1998-4131

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)
This report represents the input data assembled by some 70 participants of the Manufacturing Cost Reduction Study. This publication consists of the following reports: 1) Steering Committee Report, 2) Primary Aircraft Structures, 3) Secondary Aircraft Structures, 4) Nonrotating Engine Components and 5) Rotating Engine Components. It is felt that this study effort has provided a solid foundation or point of departure for future independent and/or cooperative cost reduction action of Government and Industry. During the course of the study, ideas, concerns, and awarenesss of problems were brought about which are bound to spawn cost reduction consciousness and action which will pay dividends. It is very important that this excellent start be followed-up by a continuing and concerted effort on the part of both Government and Industry.

14. SUBJECT TERMS
Titanium, turbine blades, aluminum forgings, aircraft structure

15. NUMBER OF PAGES
356

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500 COMPUTER GENERATED STANDARD FORM 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

TABLE OF CONTENTS

TABLE OF CONTENTS - Continued

FOREWORD

This report represents the input data assembled by some 70 participants of the MANUFACTURING COST REDUCTION STUDY who met during the week of 28 August 1972 at the Sagamore Conference Center, Sagamore, New York. The participants represented key management and technical specialists from 25 Industrial Firms and several Air Force organizations.

This publication contains the Study Reports prepared by the Steering Committee and the Panels. These reports are contained in the following sections:

PART A - Steering Committee Report

PART B - Primary Aircraft Structures

PART C - Secondary Aircraft Structures

PART D - Nonrotating Engine Components

PART E - Rotating Engine Components

Summary information on the conference organization, management and list of attendees is included in Part F - Appendix.

INTRODUCTION

A SUMMARY OF THE KEYNOTE ADDRESS

by Dr. A. M. Lovelace

Director, Air Force Materials Laboratory

During the past decade, National Defense has decreased from 50% to 30% of the National Budget. Though total military spending has taken only modest cuts, inflation and salaries have drastically reduced the buying power of the funds. What is more frightening, however, is that in relation to the modest overall cuts, more severe cuts in military spending are likely over the next year. Funding decreases and growing salaries have reduced the procurement of weapons systems, research and development, construction and sundry supplies and services from $45.4 billion in FY 1968 to $36.4 billion in FY 1972. When inflation is considered, the drop in available procurement funds has been over 30%. On top of this, the decrease in spending by NASA and the commercial airlines has resulted in over a 50% decrease in spending power within the aerospace industry. It is quite clear that the period of Defense dominance of manpower and public spending trends has passed. We are going through a transition period of moving from a wartime economy to a peacetime economy. The tooth fairy syndrome of anything you ask for you are given is a thing of the past. As we move through these periods of transition, there are many challenges that must be faced. One of these challenges is to maintain military superiority within severe budget restraints while one unit cost of weapons has increased by a factor of six within the last twenty

years even without the effects of inflation. In WW II, a P-47 cost around $100,000. An F-104 built between 1954 and 1963 ran around $2,500,000. The cost of an F-15 will be in the range of 10 to 15 million dollars. Over thirty years, we have had more than a 100 fold increase in aircraft system cost. Industrial commodities rose 22% in the 1961-71 period while weapon systems in general were rising 300%. Aircraft fighters were increasing in cost by an even more spectacular rate of 500 to 600%. These soaring costs have forced the Pentagon to buy fewer weapon systems and to purchase fewer units of those systems it decides to produce. We can argue that it is the increased sophistication that is so costly, but many people are beginning to believe that perhaps the increases in costs are resulting in only marginal increases in capability. Dr. John Foster, Jr., Director of Defense Research and Engineering, recently discussed this problem. He stated that "oversophistication of weapons hurts productivity and cuts into the total defense available -- improved technology is often required to meet the threat, and in a real way can contribute to the kind of productivity I have in mind -- we must always remember that our goal is usable output, not just bigger and better and not just more sophisticated. Usable output is the key". With this in mind, the words earlier this year of Senator Stennis, Chairman of the Armed Services Committee, should fit the framework of thought for this conference: "If the weapons we develop are so costly that we cannot afford enough of them, and if they are so technically complex that they are unreliable and difficult to maintain, we have done the Nation a disservice by developing them". These words highlight the reason for this conference.

The objectives of the Sagamore Conference - Air Force/Industry Manufacturing Cost Reduction Study are:

1. Quantitatively and qualitatively defining the cost of major airframe/aeropropulsion structural components (step-by-step),

2. Determining the best approaches for significant end item acquisition cost reduction, while maintaining present reliability and performance, and

3. Defining specific activities to demonstrate cost saving approaches.

The results of this study will provide a framework for future program planning.

Thus, it is perhaps time we stopped considering defense budget cuts a disservice to us and think more of the disservice we have done the public through the development of extremely costly weapons. It is time to face up to the revolution of thought that has taken place. It is time we accept the fact that we are operating in a new environment. Our response should not be a sacrifice of performance or quality, but an arousal of energy into ways of reducing costs to lessen the burden of each defense dollar. We must do what we do more economically than we have in the past.

The message for us here at Sagamore is clear. Building aircraft weapon systems is like building a three-legged stool. The three legs necessary for a stable stool are performance, reliability and cost. There must be trade-offs made between the three variables in order to assure that all three legs are the same length. In the past we have built a one-legged stool. The stress in the early 60's was heavily weighted towards performance.

This approach was perhaps narrow-minded but resulted in numerous technological advancements. Unfortunately, being narrow-minded and shortsighted precluded observance of possible problem areas. It seems that performance in some cases had come at the expense of reliability and suddenly the new "hot biscuit" became reliability. Fracture mechanics and similar technology became the bandwagon. But a two-legged stool is little more stable than a one-legged stool. Both of these legs involve costs in real dollars. It is time we emphasized the third leg - cost. We must obtain an understanding of cost in relation to performance and reliability to place it in its proper perspective. We recognize that this is not an easy task. This involves not only understanding the cost of a system but also understanding the value of performance and reliability. Since we can only consider so many variables at one time, it is necessary that we accept certain current day values of aircraft performance and reliability in order to evaluate techniques for reducing costs.

I expect and encourage each of you to participate with an openness that may be unprecedented for this type conference. I don't expect miracles this week but I expect a lot of hard work that can be the foundation of a much larger change in aerospace manufacturing attitudes. I hope to see identification of areas in which the Air Force can wisely invest money to substantially reduce the cost of manufacturing aircraft systems. I hope to see you leave here with a change in attitude towards the importance of cost in military systems. If we succeed in the preceding we will have accomplished two things:

1. A reduction in system cost, thereby a more efficient utilization of resources. This may be the start of a new syndrome, a more-for-

your-money syndrome. This does not seem, however, to be such a bad concept on which to spend our efforts and funds.

2. A rebuilding of public confidence in:

a. Managerial expertise within the military/industrial complex.

b. The fact that public funds are being spent efficiently.

c. The importance of military system development, and thus our existence.

PART A

STEERING COMMITTEE REPORT

I. AIRFRAME SUBCOMMITTEE

Airframe structural components are expensive because (a) they are made of a large number of detail parts and subassemblies and have a large number of holes and fasteners, and (b) a large number of man-hours is required to assemble the details and major assemblies for a given pound of structure. This conclusion is the result of the efforts and data provided by 60-70 Industry and Air Force representatives on the conference panels and is consistent with the experience and data of the members of the Steering Committee. Data and facts which lead to this conclusion are as follows:

a. 30% to more than 70% of total manufacturing costs are attributable to subassembly and assembly man-hours.

b. Subassembly and major assembly manufacturing man-hours are almost directly proportional to the number of detail parts, the number of holes for joining required, and the number and types of fasteners required.

c. Items a. and b. above indicate that reductions in part numbers, holes, and fasteners are in order.

d. Together, a., b., and c. imply that a "unitized" design is needed to accomplish these goals. There must be larger units of components, a minimization of discontinuities, and larger (in weight and configuration) wrought, cast, or forged products entering as initial

manufactured elements.

e. To achieve the needed reduction in holes, fasteners, discontinuities, and the like, implies that more machining must be done. Thus, a reduction of machining costs provides the next goal.

f. Recognizing that all holes and fasteners cannot be eliminated, we must continue to address cost reductions in hole preparation and reduction in the numbers of types of fasteners. Reduction of the number of types of fasteners (standardization) provides advantages in reduced purchase price, inventory costs, process or installation methods development, training, and inspection methods - in addition to costs such as life cycle logistics and the like.

g. Figure A-1 depicts the above, plus additional items to consider or pursue for further manufacturing technology development.

h. Also, included on Figure A-1 is an enumeration of the most obvious implications on engineering design.

Another cost driver is the high cost of quality assurance which has in the past accounted for 10% to 22% of manufacturing man-hours. Two opposing forces are involved here, as shown in Figure A-2. The desire to reduce manufacturing costs is an incentive to drive inspection costs down while added requirements to identify very small flaws in high strength, brittle material tends to drive costs up. Several approaches to the solution of this dilemma are promising. Automated high speed computerized ultrasonic techniques could provide a much needed capability, however, transducer improvements are badly needed. Another cost saving

Figure A-1. Major Cost Drivers - Airframe Structures (Priority No. 1)

P. STRUCT.
S. STRUCT.
PROPULSION

SUB-ASSEM., ASSEMBLY M-HRS. DRIVE COSTS: <u>30-73% OF TOTAL COSTS</u>

REDUCE NO. OF:
<u>PARTS</u>
<u>FASTENERS</u>
<u>HOLES</u>

INFERS MORE MACHINING

AND/OR

REDUCE MACHINING COSTS:

a. HOT DIE FORGINGS
b. DIFFUSION BONDING
c. WELDING

HOT DIE DEVEL.

d. CUTTER DEVEL.
(1) FINISH
(2) SPEED
(3) COOLING FLUIDS
(4) MAT'LS

e. CUT BLENDING
f. ESTAB. REALISTIC FINISH REQMNTS.
g. FORM HEAVY PLATES FOR CONTOUR

REDUCE HOLE PREP. COSTS

REDUCE NO. OF TYPES OF FASTENERS

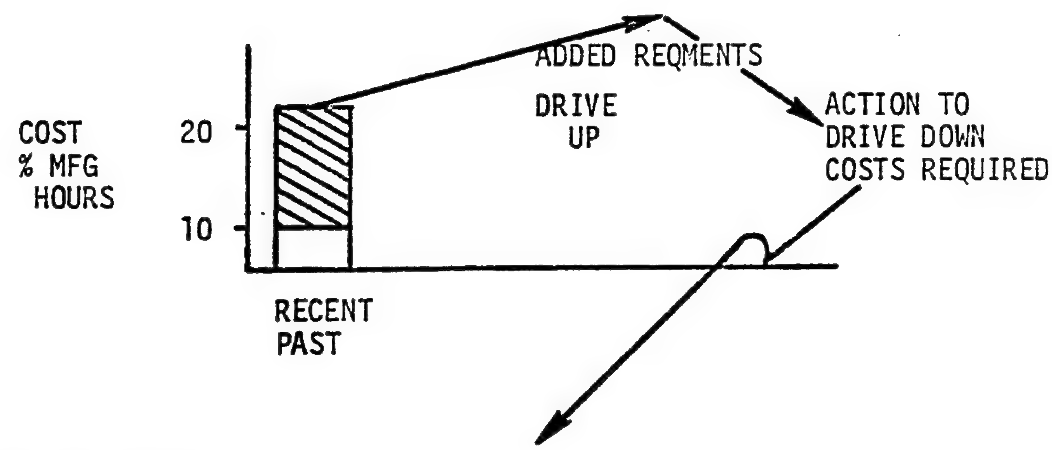
REDUCE DEBURR
NON-CONTAMINATING FLUIDS
PREVENT CONTAMINATING FLUIDS
PREVENT DESTACKING
COLD WORK - REDUCE SENSITIVITY TO SMALL FLAWS

<u>DESIGN IMPLICATIONS</u>

a. FEWER JOINTS TO DESIGN, ANALYZE AND TEST
b. REQUIRES DESIGNER TO FULLY ACCOUNT FOR DETAILS OF MANUFACTURING
c. MAY REQUIRE LARGER DEVELOPMENT AND PRE-PRODUCTION VERIFICATION TEST SPECIMENS
d. FEWER ENGINEERING DRAWINGS TO MAKE, MAINTAIN, ETC.
e. MRB SALVAGE MORE DIFFICULT

HIGH COST OF MANUFACTURING QUALITY ASSURANCE

(10-22% of Mfg. Man-Hours)



- FOR EXAMPLE:

  1) Automated High Speed Computerized Ultrasonic Inspection
  2) Computer Controlled Dimensional Inspection
  3) Inspection Criteria-Effects of Defects (e.g., Criteria by Part Zone)
  4) Method to Detect & Characterize Small Defects

Figure A-2. Airframe Cost Drivers

technique might be computer controlled dimensional inspection, or a combination of flaw detection and dimensional inspection. Inspection criteria which would better assess the effects of defects could reduce inspection cost through the establishment of critical part zones. A method to detect and characterize small defects with respect to size, shape, and orientation is also required. A significant cost driver of quality assurance is the proliferation of inspection costs as the material passes through the production cycles from "melter" to "forger" to "fabricator/machiner" to "user". The act of standardizing methods to arrive at an acceptable certification procedure from operation to operation is essential for the elimination of duplication.

As a result of the work done by the panels, it was found that material costs accounted for from 10% to 50% of the finished product, depending on the type of part or structure. Also, the scrap generated in processing from alloy melt through finished part manufacture was found to be from 30% to 90% of the starting material. At the present time there is relatively little reclamation of machining scrap. Certain alloys, because of their high cost (e.g., titanium) appear to warrant some attempt to scale-up scrap reclamation so that the value of scrap increases, resulting in a net reduction of total machining costs. For the case of titanium which is found in quantity in the United States only as low grade ore, reclamation of scrap will reduce imports and help make the Nation more self-sufficient.

Historically, titanium alloys have demonstrated a much higher scatter in fatigue performance than either steel or aluminum alloys (see Figure A-3). More recently, it has been found that with the introduction of

- RECLAMATION OF SCRAP, CHIPS (e.g., TITANIUM)
- FATIGUE/FRACTURE INCONSISTENCY OF TITANIUM: IMPROVE THROUGH CHEMISTRY, THERMO-MECHANICAL PROCESS CONTROL, AND ALLOYING ELEMENT VARIATIONS

  PROBLEMS:

  - MATERIAL REJECTION
  - LARGE SCATTER FACTORS REQUIRED
    - * VARIABILITY Ti vs Al = 2.0

      Ti vs STEEL = 2.7
  - QUALITY CONTROL EXPENSE

Figure A-3. Airframe Cost Drivers

fracture mechanics procedures into titanium specifications, the producers are having difficulty controlling the variation of fracture toughness within acceptable limits. The result of this scatter in fatigue and fracture toughness properties is either additional weight (to take into account the scatter factor) or an increase in inspection requirements and material rejection. It is strongly recommended that additional development of the interacting effects of chemistry (trace elements), alloying element variations, and thermo-mechanical processing be investigated. At this time it is not possible to obtain duplicative data from different sources of analytical analyses on trace elements. Thus, the desire to measure effect is compounded by the major difficulty of inconsistency.

II. PROPULSION SUBCOMMITTEE

The Sagamore Conference identified many factors which drive the cost of Air Force systems upwards. The participants were quite consistent in identifying high cost areas and are in complete accord with the Department of Defense and the USAF in the philosophy that tight schedules and the ultimate in performance regardless of cost is no longer an acceptable way of life.

The Steering Committee wishes to note some significant factors contributing to high cost, even though the Sagamore study was restricted in its Charter in item d., below.

a. System requirements - long life, maximum performance, very high thrust/weight ratios.

b. Procurement methods - small quantities, short development time.

c. Design practices - super-precision parts, material selection, complex forms, retaining previously substantiated practices.

d. Materials processing and manufacturing methods.

Through much hard work, preparation and excellent cooperation of each of the panel members, the objectives established for the study were fully accomplished, even though these appeared ambitious for the limited time available.

All of the information presented is in terms of percent cost of complete engines. The Materials Laboratory will have the capability of relating these findings to real dollar values at a future date by obtaining data from each contractor individually. To set the framework for a data base, Tables A-I and A-II present a breakdown of costs of several types of current engines. Since the data from the several engine contractors was not available in exactly the same category breakdown, a firmer base could result if the USAF established a standardized breakdown and obtained data in this form from each contractor.

The two engine panels studied specific engine parts representing a small portion of total engine cost. Extrapolating this to all similar engine parts indicates that their findings are applicable to about 50% of engine cost. Many items contributing to engine cost, such as fuel controls, pumps, assembly and test, do not appear to be significantly affected by improvements in manufacturing technology. Excluding these items, it appears that the Air Force Materials Laboratory could

TABLE A-I. ENGINE COST BREAKDOWN (%)

COMPONENT	LARGE TURBO-FAN	SMALL TURBO-SHAFT	AUGMENTED TURBO-FAN	LARGE OLD JET	SMALL OLD JET
DISKS & SHAFTS		18	16	12	7
AIRFOILS	29	17	14	14	10
FRAMES & SUMPS	19	16	16	18	7
CASING & EXTERNAL HARDWARE	14	7	10	13	7
COMBUSTOR	2	3	1	.5	3
AUGMENTOR/EXHAUST NOZZLE	0	1	19	13	13
CONTROLS & ACCESSORY DRIVES	7	24	10	17	37
CONFIGURATION HARDWARE	3	4	4	3	6
ASSEMBLY AND CLOSURE	10	10	10	9	10
TOTALS	100	100	100	100	100

TABLE A-II. ENGINE COST BREAKDOWN (%)

NAME	MEDIUM SIZE TURBOSHAFT ENGINE	LARGE TURBOSHAFT ENGINE	UNAUGMENTED TURBOFAN
COMPRESSOR	33.2	34.4	45.4
TURBINE & COMBUSTOR	30.6	28.7	34.6
ACCESSORY GEAR BOX	3.2	3.1	3.4
FUEL, LUBE & AIR SYSTEMS	19.6	24.2	9.5
ASSEMBLY & TEST	7.4	7.9	4.9
MISCELLANEOUS	6.0	1.7	2.2
TOTALS	100.0	100.0	100.0

effectively apply cost reduction efforts to approximately 75% of engine cost. It appears therefore that this study at Sagamore has explored approximately two-thirds the potential cost reduction area (see Tables A-III and A-IV). Thus, future studies might attack the approximately 25% of engine cost not yet explored. Some examples of high cost areas for future review are honeycomb ducts, augmentors and variable area exhaust nozzles.

Many of the significant cost "drivers" uncovered are common to both rotating machinery and static structures, and, in fact, to certain air-frame structures. Some examples of these are:

1. The very low finished part to input weight fraction experienced in forged parts, coupled with poor recycle capability.

2. The high cost of metal removal in all phases of the operation from ingot to finished part.

3. Redundancy of inspection operations.

A rough estimate of the maximum potential savings in engine cost obtainable through items identified in this study is presented in Table A-V. This is presented as a target, since a very detailed study would be required to establish the true potential.

One task required of the Steering Committee was to provide a priority list based on the findings of the Propulsion Panels, so that the Materials Laboratory can direct future development efforts to the most fruitful cost reduction areas. We were not able to do this, since we could not assign true dollar potential cost savings to the items studied,

TABLE A-III. SCOPE OF ENGINE STUDY

			EXPLORED % OF TOTAL ENGINE COST*
ROTATING COMPONENTS			
Turbine Disks	4-8		
Compressor Disks	8-12		
			12-20
Turbine Blades (Hollow)			
Turbine Blades (Solid)			
Fan Blades Midspan Damper			
Non Midspan Damper			20-30
NON-ROTATING COMPONENTS			
Combustor			
Compressor Case (Frame)			1-3
Midframe (aft case) Superalloy			7-10
		**Total	40-63
			UNEXPLORED
Assembly & Test			15-30
Controls & Augmentors			15-30
		**Total	30-60

*INCLUDES parts studied plus all similar engine parts

**% range reflects the variation in cost depending upon engine size; fan or shaft

TABLE A-IV

PERCENT OF TOTAL ENGINE COSTS WHICH COULD BE AFFECTED BY AIR FORCE MATERIALS LABORATORY COST REDUCTION PROGRAMS

		% of Engine Cost
TURBO FANS		
Fan & Compressor		45
Turbine & Combustor		35
Accessories		3
	Total	83
TURBO SHAFT		34
Compressor		29
Turbine & Combustor		3
	Total	66

TABLE A-V

ESTIMATED COST REDUCTION POTENTIAL

SPECIFIC AREA	% OF ENGINE COST
Materials	
Scrap Reclamation	
Compressor Mat'l (Ti)	3
Superalloy	1
Coatings	1
Machining	
Hole	1
Turning (Reduce 50%)	10-15
Quality Control	
Specifications and Redundancies	5
Benching	
Deburring; Polishing	2
Fit-up	1
Tools	
(Relate to Machining)	
Schedule Compression	2
Improved Quantity Determination	
	25

and since any such list should be tempered by an assessment of the probability of success.

The Steering Committee recommends the following actions in the Propulsion Area:

1. Continue the studies begun at Sagamore to complete a data base, placing first emphasis on those engine elements not studied either directly or by similarity to the initial study. Provide each of the Sagamore participants with the generated data as a guide for this continuing study.

2. Obtain individually from the participating contractors real dollar data to completely define and confirm the priority conclusions reached by the individual propulsion panels. Integrate this base with similar airframe data to obtain a firm system data base to establish system cost reduction priorities.

3. Implement materials processing and manufacturing technology programs in those identified areas as having the greatest cost reduction potential in accordance with the priorities as finally established.

PART B

PRIMARY AIRCRAFT STRUCTURES
PANEL REPORT

I. PRIMARY STRUCTURES AIRPLANE COSTS

A. Medium to Large Commercial/Military Transports

In order to gain a perspective of primary structure airplane costs and to intelligently address high cost areas, an understanding of cost distribution is desirable.

Figure B.1 shows the traditional manufacturing hour per pound values for aircraft primary structure components. The shaded part of the bars show a range of values for the aircraft included in the study. The man-hours per pound can in itself be misleading when looking for sources for cost reduction. It is necessary to look at both the hours per pound and the total pounds to determine costs.

This effect is illustrated in Figure B.2 where the percent of structure component weight and cost vs. total airplane structural weight and cost indicates that the wing and fuselage components are highest in weight and costs and that the wing box and fuselage midsection, respectively, are the high cost contributors. This is contrary to their low hours per pound values.

Figure B.3 shows the distribution of weight and cost within the fuselage shell structure. The total shell is shown along with a breakdown of the major components within the shell. Skin panels are seen to be a primary cost element with assembly being dominant. The general arrangement

Figure B.1. - Aircraft Manufacturing Hours Distribution

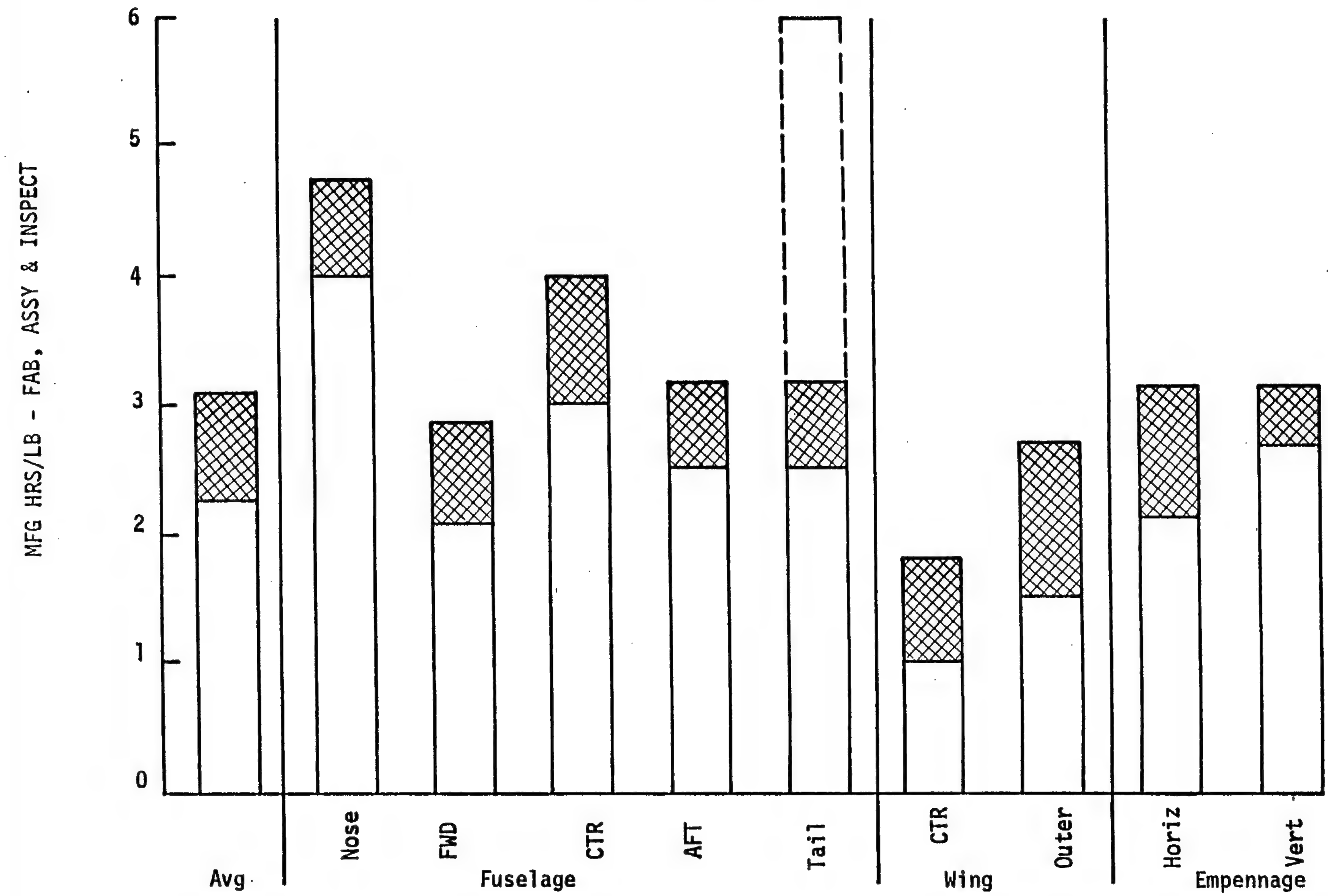


Figure B.2 - Transport Structure Weight & Cost Distribution

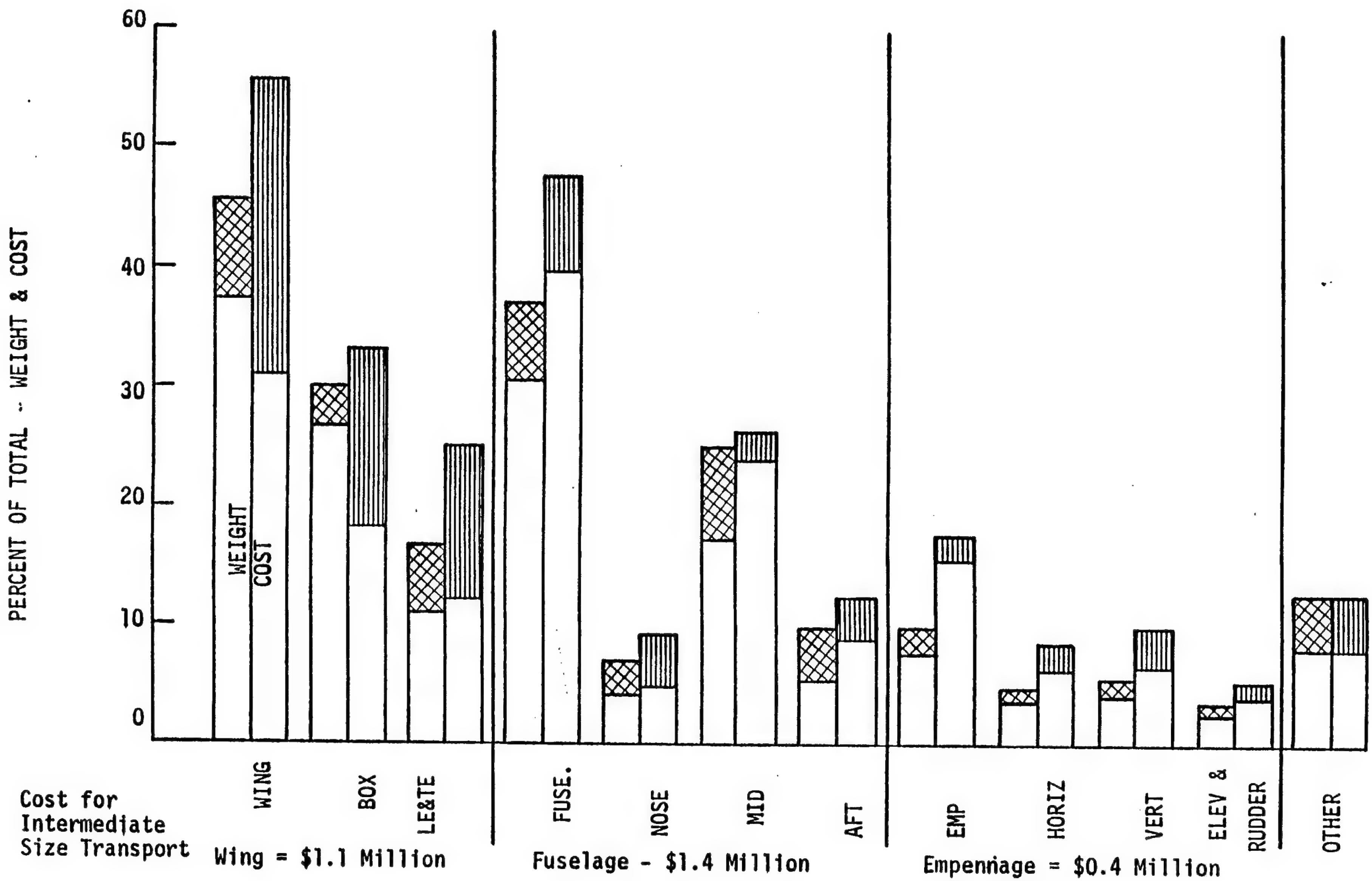
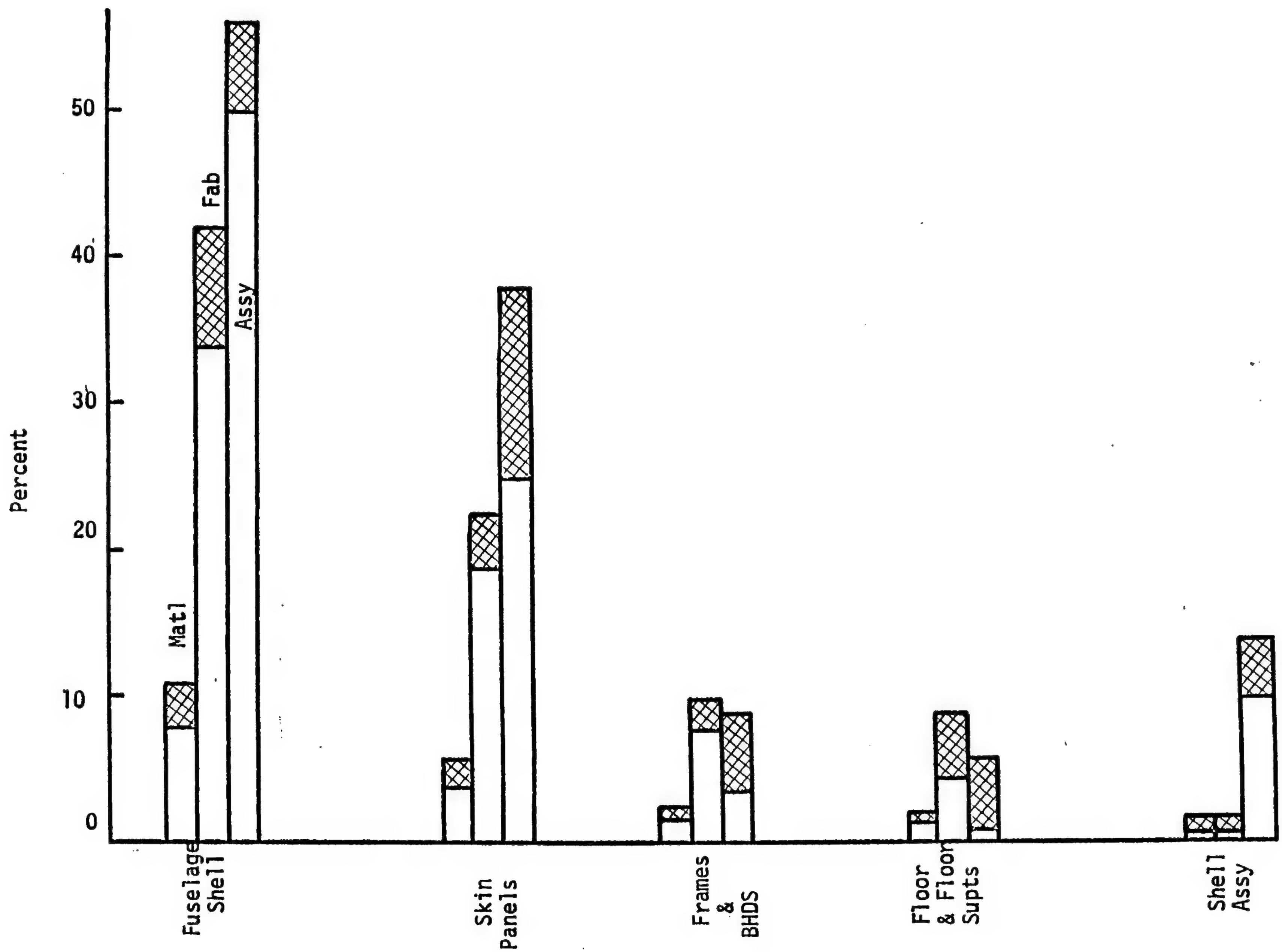


Figure B.3 - Fuselage Shell Cost Distrilution



of the fuselage shell is illustrated in Figure B.4. This is typical of large transport type fuselages.

Figure B.5 shows a similar breakdown for the wingbox. Less data were available for this breakdown and no ranges of values are shown except for material. The difference in material costs results from design difference in panels where integrally stiffened panels require more material than wing panels built up from skins and stringers. Again, assembly costs are shown dominant.

In Table B.I a breakdown of costs for a Subsonic [illegible] Front Spar is shown. This 413 pound aluminum spar is typical in complexity for much of the wing primary structure. Through this Table it is shown that a very large part of the total cost of the structure is related to a large number of small detail parts that must be fabricated and assembled.

Of the 138 fabrication hours, 74% is required to make the many small details. The chords and webs, even though they are 70% of the weight, use only 26% of the fabrication hours. The 283 assembly hours are a result of the large number of small parts rather than the three large parts.

From this and other studies, it can be concluded that very significant cost savings can be made through the combined engineering and manufacturing evolution of simple reliable designs that significantly reduce the number of parts that need to be fabricated, processed and assembled.

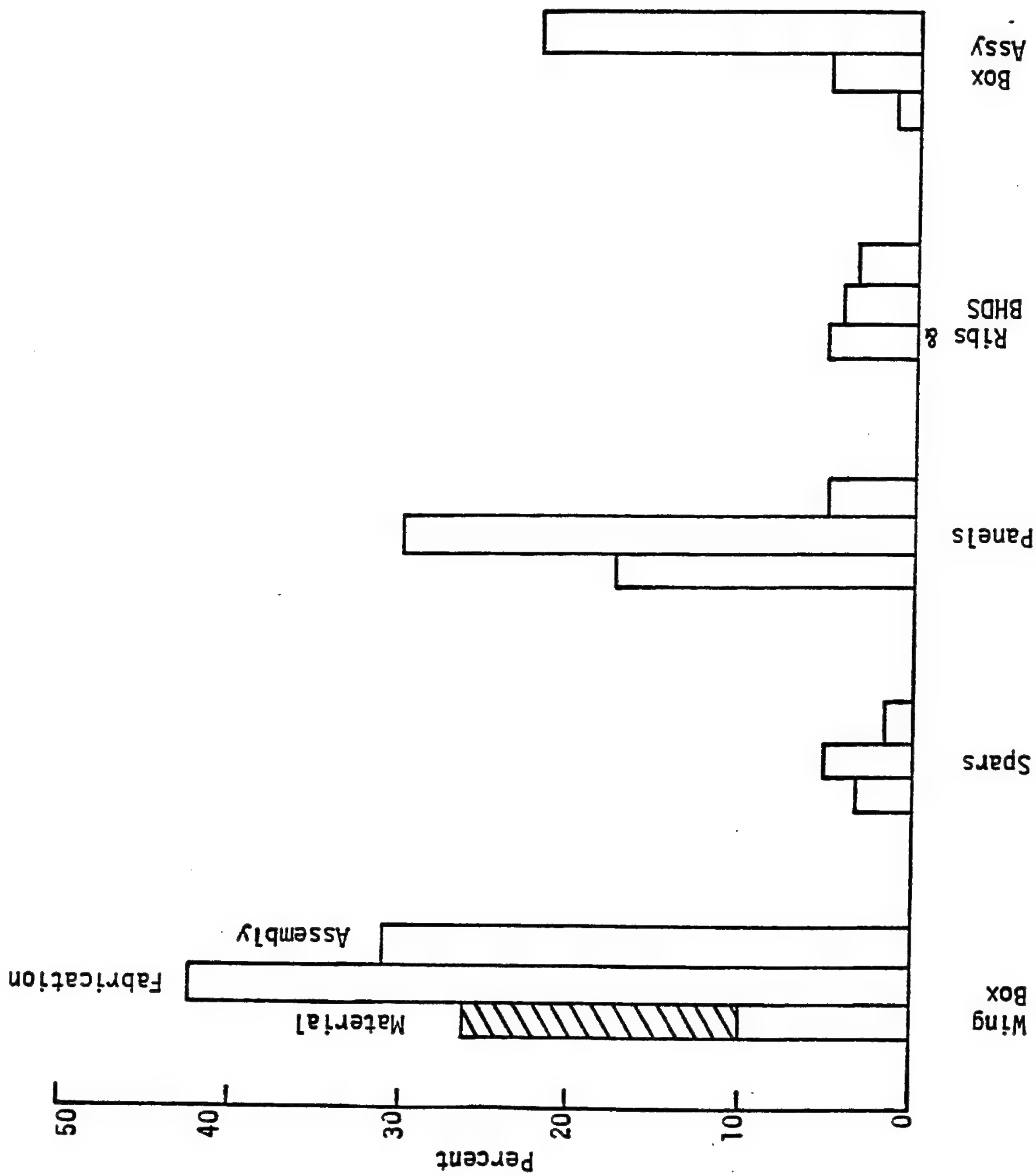


Figure B.5 - Wing Box Cost Distribution

TABLE B.I SUBSONIC JET FRONT SPAR (413# ALUMINUM PART)

ITEM DESCRIPTION	PART WEIGHT	LABOR	TOTAL
RECURRING COST (200 A/C Ave)	(LB)	(HRS)	($)
1. Material Cost (Est. $7.00/lb x 413#)			2,891
2. Production Labor			
a. Part Fabrication (138 Hours)			
(1) Upper Chord (Raw Extr. 417#)	88		
Machine		15	
Form		1	
Finish		1	
(2) Lower Chords (Raw Extr. 413#)	63		
Machine		8	
Form		1	
Finish		1	
(3) Web (Plate Stock 700#)	140		
Machine		8	
Finish		1	
(4) Detail Parts	96	102	
b. Assembly			
Labor		283	
Fasteners/Sealant/Misc	26		
c. Other Labor (Engr/Mfg. Support, Quality Control)		189	
Total Unit Cost (Ave 200 A/C)	413		
Labor @ $20.00/Hr		610	12,200
Unit Ratios		(1.48 Hr/#)	($29.60/#)
Non-Recurring Cost			
Labor (200A/C, 98,229 hrs, $2,078,326)			
Per Aircraft			5,196
Per Pound Ratios		(.60 HR/#	($13/#)
TOTAL PART COST			20,287
		($2.08/#)	($42.60/#)

Efforts should be directed at evolving new structure designs and the associated manufacturing methods that can reduce structure complexity and the associated costs.

In Figure B.6 is shown the Manhour Expenditure by Cost Element. A very large part of the start-up cost for an airplane production program is associated with the people becoming familiar with the airplane details or drawings and the associated production operations. On Airplane No. 1, area 7 shows that this amounts to 36% of the effort and even at Airplane No. 10 it is approximately 20% of the effort.

In all airplane programs, and particularly on the large airplanes, a significant cost saving can be made by very aggressive combined engineering and manufacturing review of ways to reduce manufacturing cost through improved designs and methods as shown by area #3 on the charts.

It is extremely important that contracts be set up so that there are funds and time for engineering and manufacturing trade-off studies in design and producibility, and that manufacturing funds be programmed into the contracts to aggressively pursue cost reduction and methods improvements as the airplanes go into production. Old approaches to program implementation will not result in reduced program production cost.

Fastener usage in the different areas of the structure is illustrated in Figure B.7. Rivets are shown in one set of bars and other fastenrs are shown in the other set (steel and titanium screws, bolts, lockbolts, etc., are included together). There are more fasteners

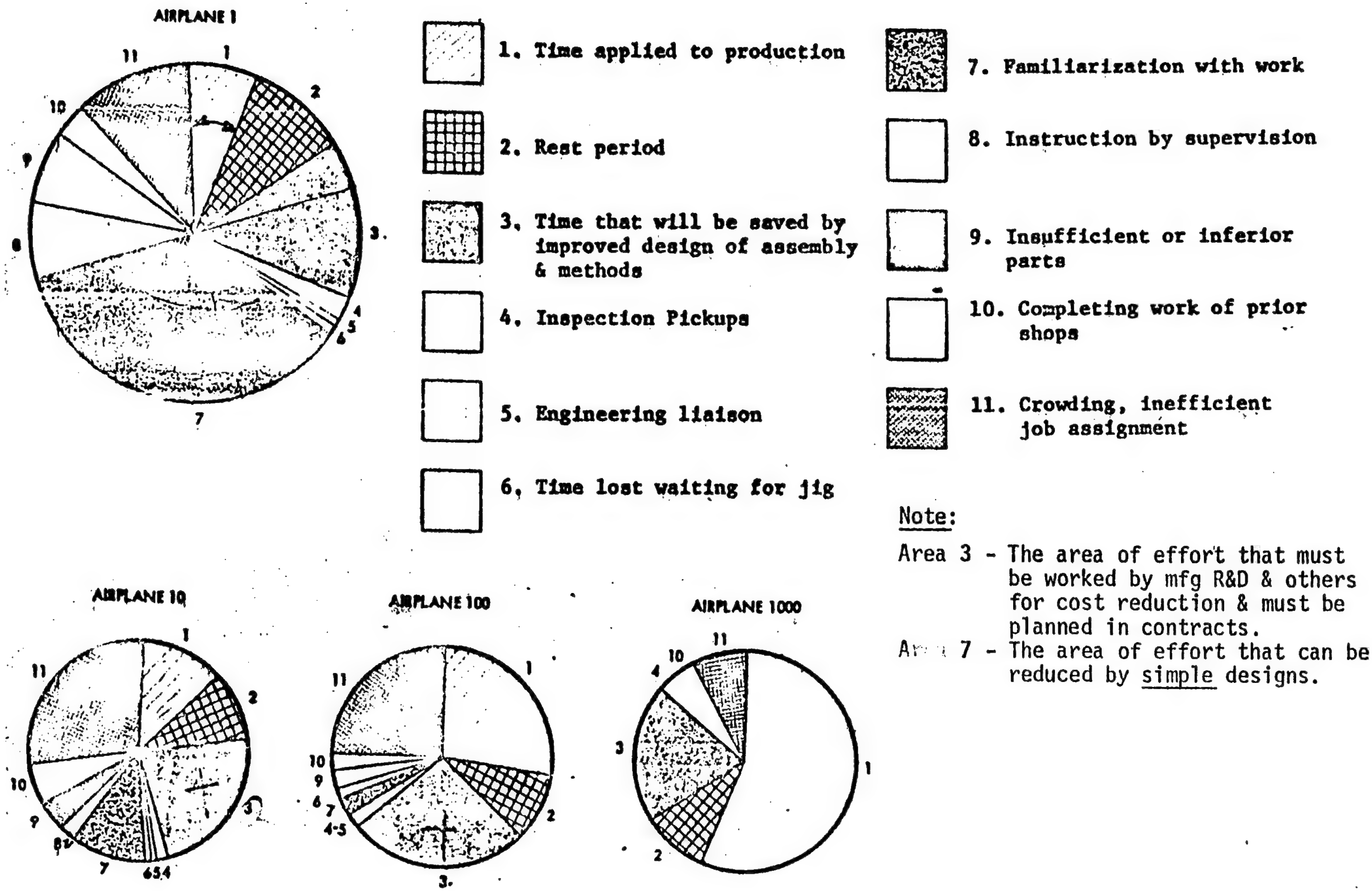
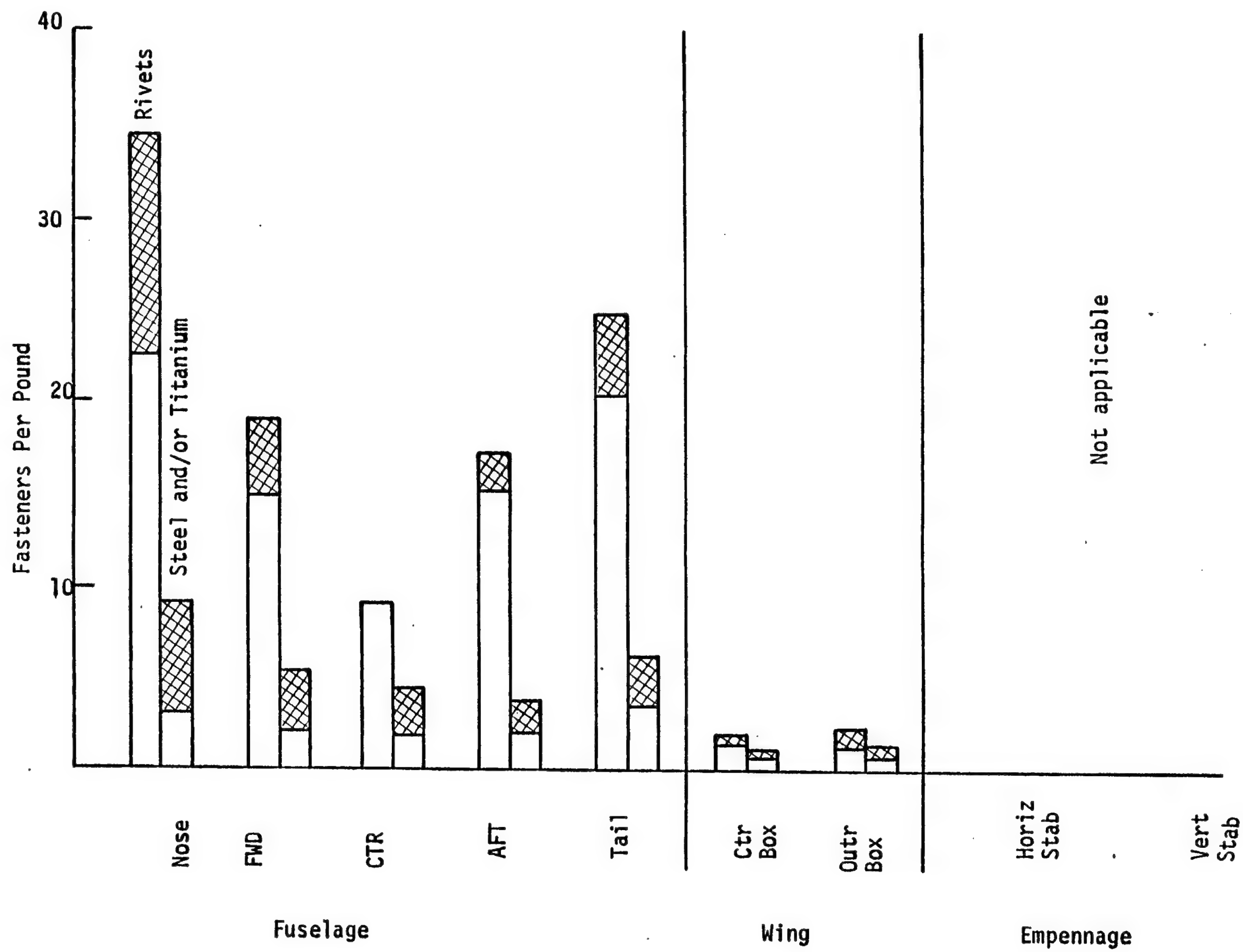


Figure B-6. Man-Hours Expended on a Typical Assembly Distributed to Elements of Cost

Figure B.7 - FASTENER USAGE



per pound in the nose section and this correlates with the low average part weight in the nose. A similar but opposite trend can be seen for the wing box. An additional effect of structural weight per unit area is evident here in that the heavier areas show less fasteners per pound. An investigation of fasteners per unit area may prove useful in further evaluation of cost vs fastener usage.

Figure B.8 shows that wherever possible hand driving of rivets should be avoided because of the high labor costs. Compromise of design in some instances to increase the use of machine driven rivets can result in reduced manufacturing costs. The relative high cost of the fatigue critical machine driven rivets is due to the relative slowness of the process compared to the general purpose machine driven rivets. However, comparing these costs with those in Figure B.9 for threaded fasteners, the high squeeze rivets are much cheaper. They are limited to total material thicknesses less than the threaded fasteners. Figure B.9 shows that when the fastener material goes up in strength, the installation costs also rise. This is also true when the structural material goes from aluminum to titanium.

While the data presented in this section represents quantity production values at the 200 airplane level, different conclusions might be suggested for cost reduction potential if limited production quantities were considered. Figure B.10 shows the relationship that fabrication and assembly labor, material cost, and inspection costs have relative to 200 airplanes. Material costs are nearly constant with regard to aircraft quantity while production labor costs assume an even more significant proportion with smaller production buys.

FIGURE B.8 - TOTAL INSTALLED COST

Al RIVETS/Al STRUCTURE

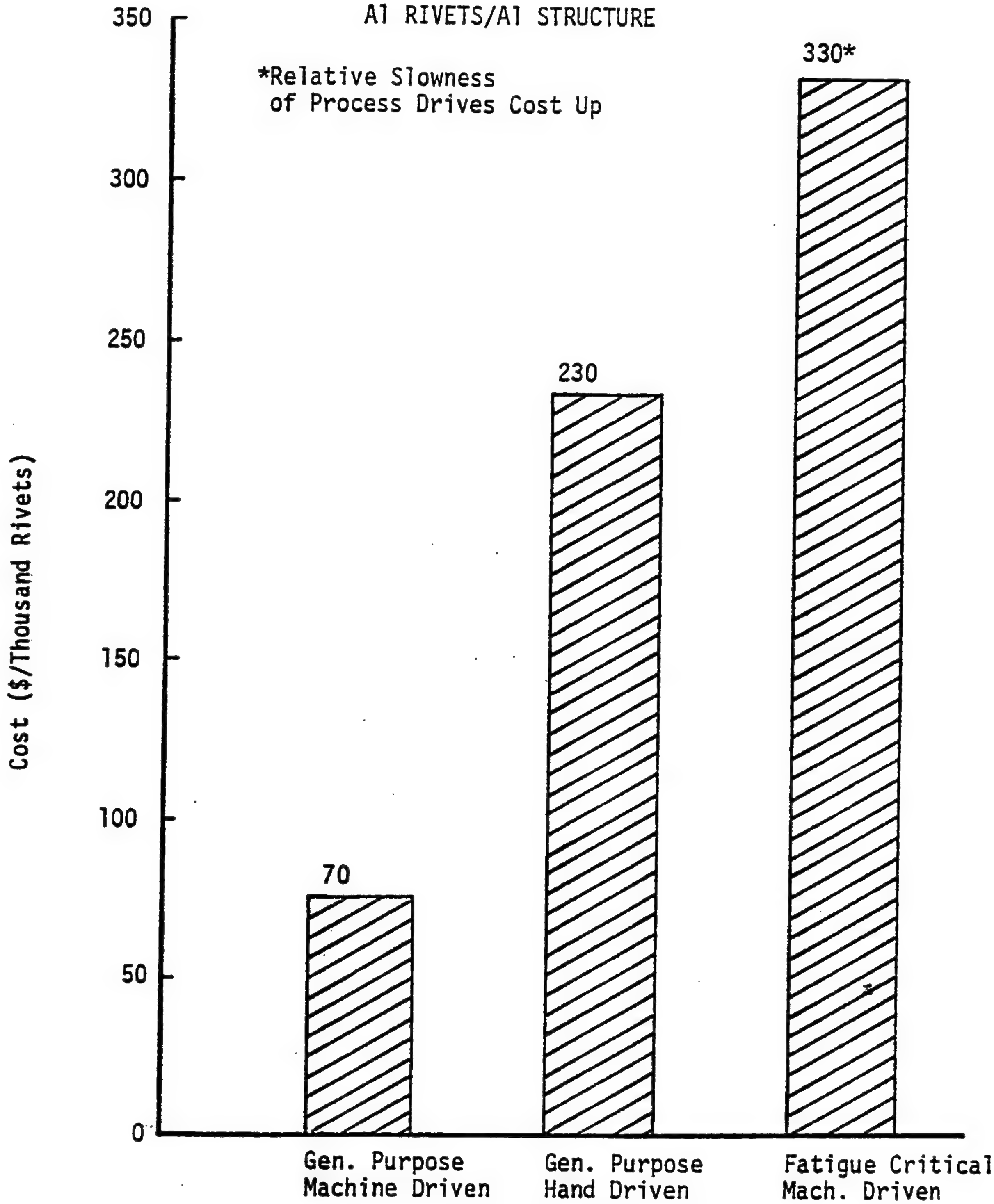


Figure B-9. Comparison of Threaded Fastener Costs

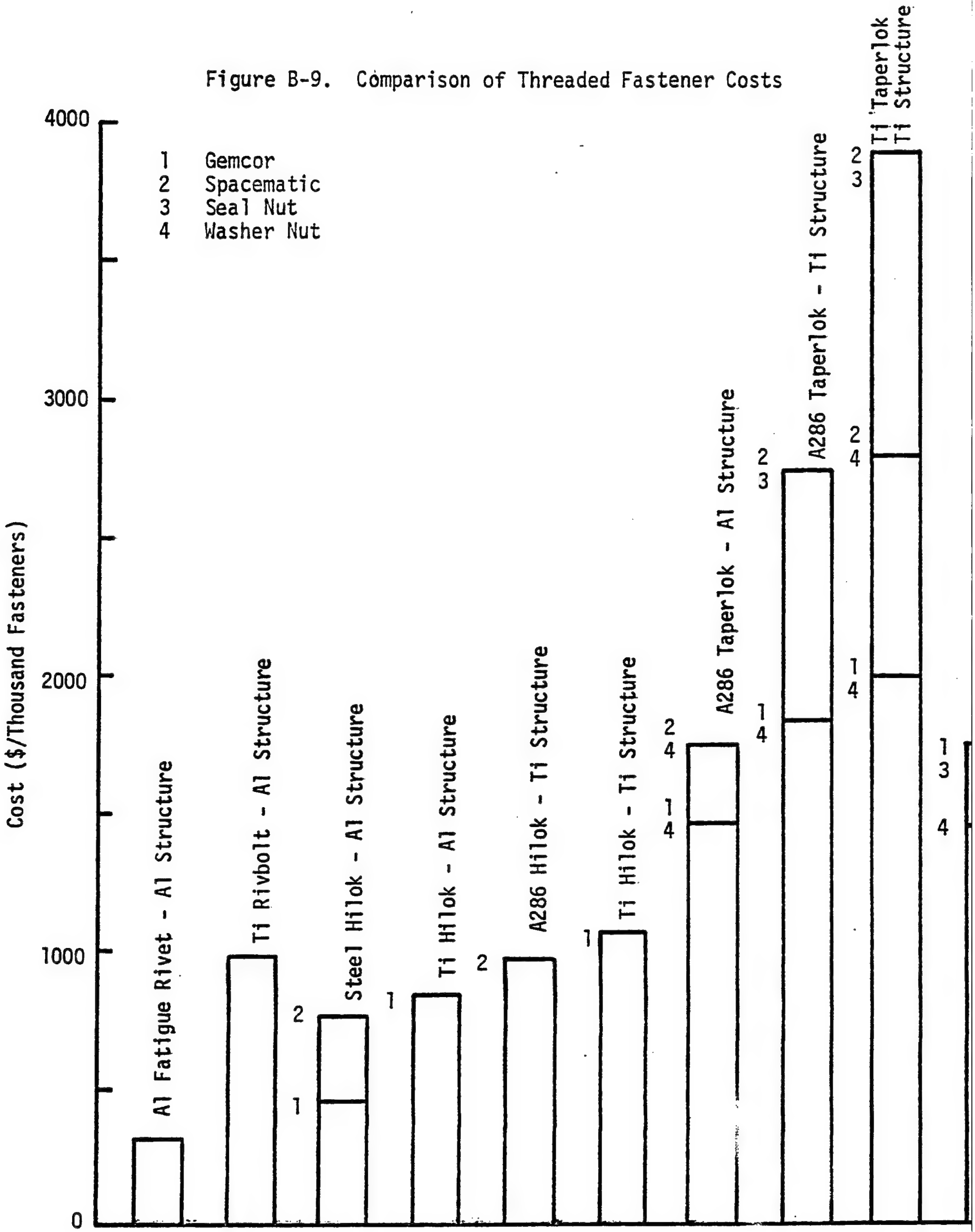
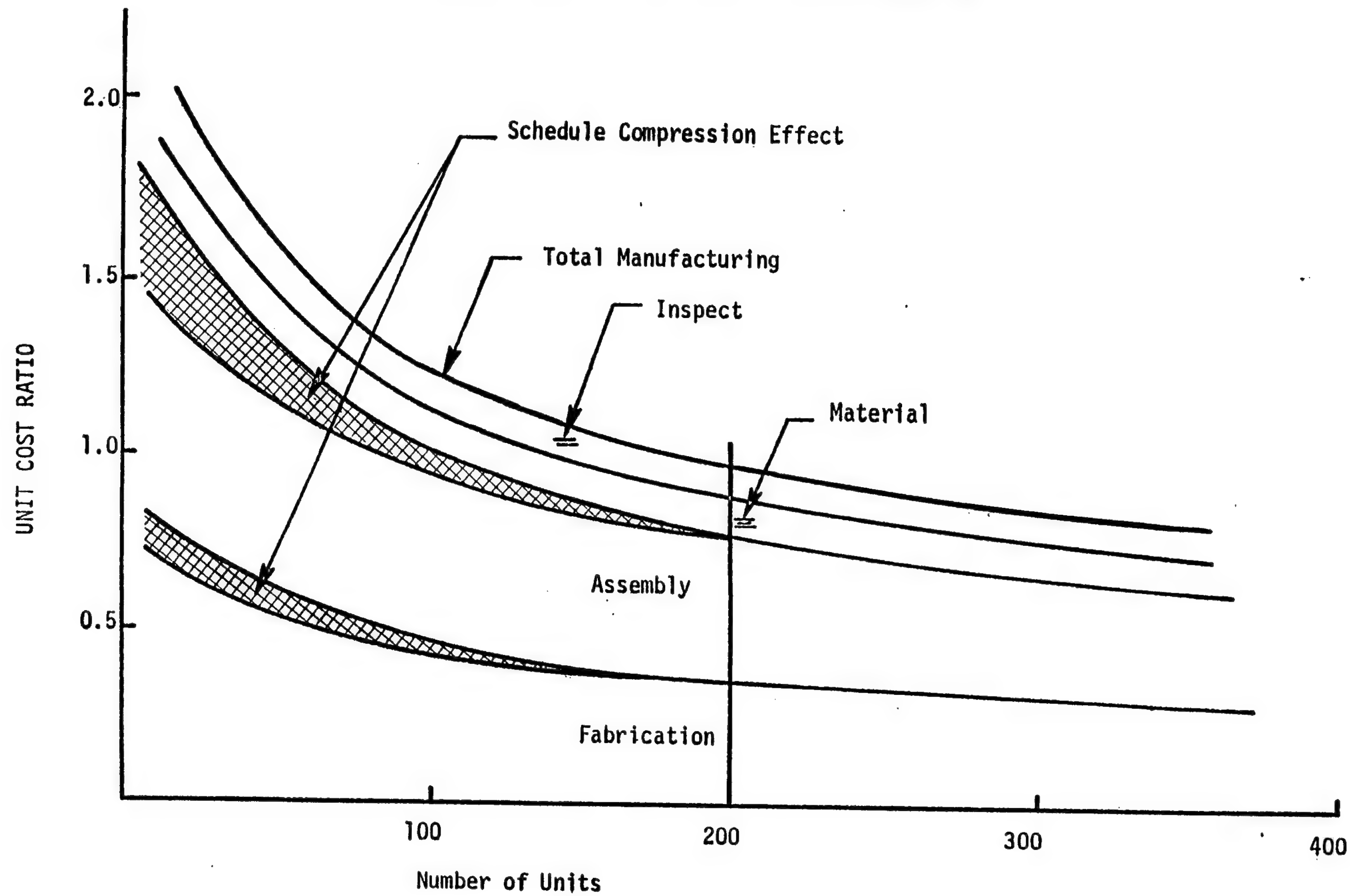


Figure B.10 - Aircraft Structure Cost (Subsonic Transport)



The shaded areas in the Figure illustrate the costs associated with a compressed schedule that requires a progressive engineering release to allow tooling and manufacturing to meet the schedule. As a result of the progressive release, a substantial number of changes is generated to revise previously released engineering which must be compatible with the remaining portion after it has been defined. Major assemblies (i.e. wing box, flap, fuselage nose etc.) should be released at one time to reduce both engineering and mfg. costs. Initial planning and schedules must provide time for this release plan.

Figure B.11 shows the impact on engineering design hours as a function of the months of preliminary design time before program go-ahead. The chart shows a 35-40% increase in engineering hours from program go-ahead to one year after first flight for a program pre-decision reduction of 7 months. Depending upon the rate of build-up, this can effect the total program cost by a 100% increase caused by changes required to obtain the program objectives. Engineering changes in turn, relate directly to scrappage of tools and parts, and manufacturing changes required because of premature engineering releases based on preliminary loads, aerodynamics and structural interface data. This effect is shown in Figure B.10 as a Schedule Compression Effect for manufacturing. The effect of these engineering changes is also shown in Figure B.11 and is the result of premature start of detail design when configuration changes occur.

A primary structure cost summary for an intermediate size transport is shown in Figure B.12. This cost data is essentially a combination and summary of Figures B.2 and B.10.

B. Fighter Type Aircraft

For fighter type supersonic aircraft, cost trends are similar to those shown in the previous discussion for transpsort aircraft. However, since design requirements are considerably more stringent and complex for fighter type aircraft than for transport types due to military use environments and regimes, the cost impact is somewhat different.

For example, as indicated on the chart in Figure B.13, the distributio of production costs for a current production supersonic fighter at the 1000 aircraft (1966 time period) is as follows:

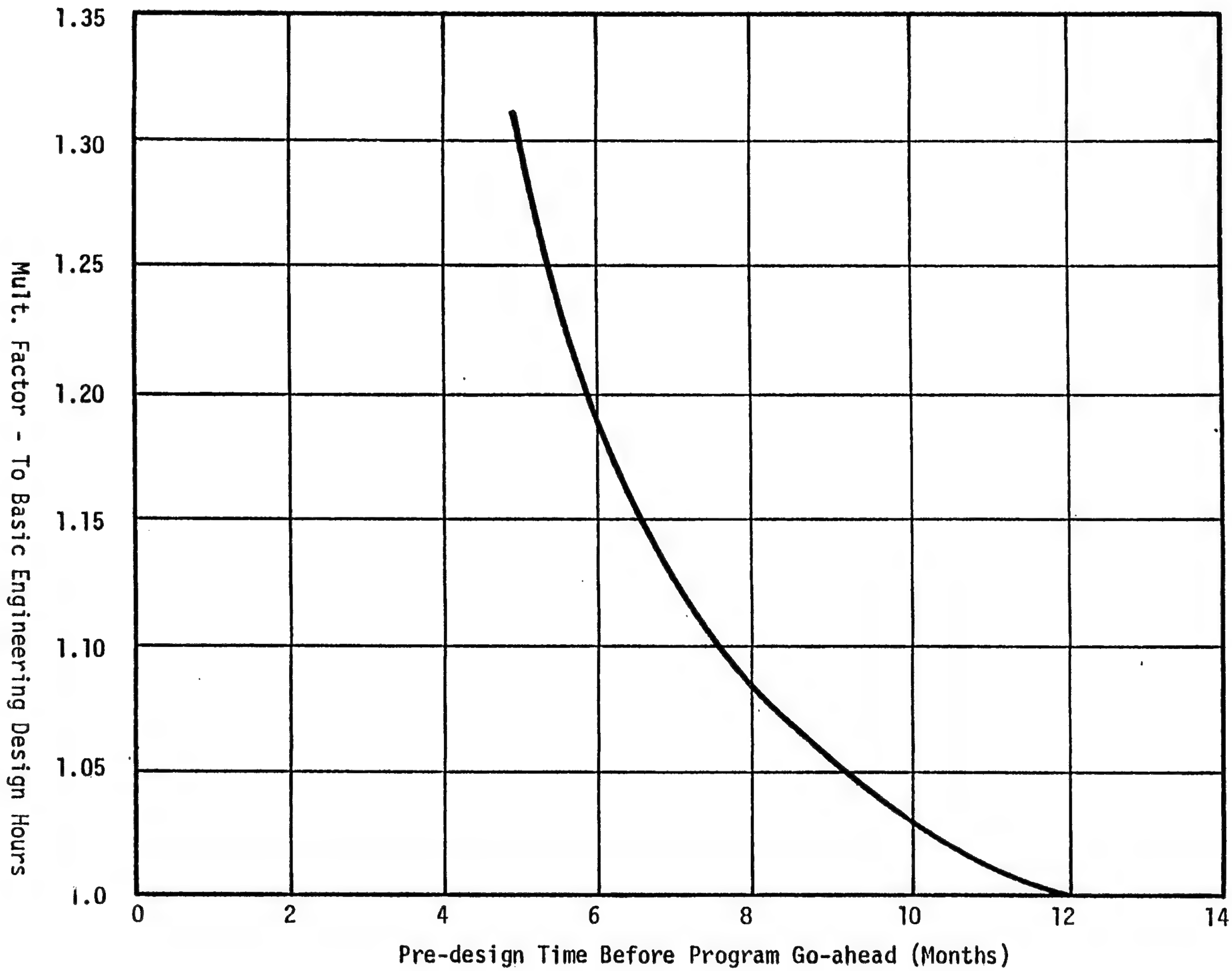


Figure B-11. Engineering Labor vs Time to Go-ahead

Figure B.12 - Aircraft Primary Structure Cost Distribution

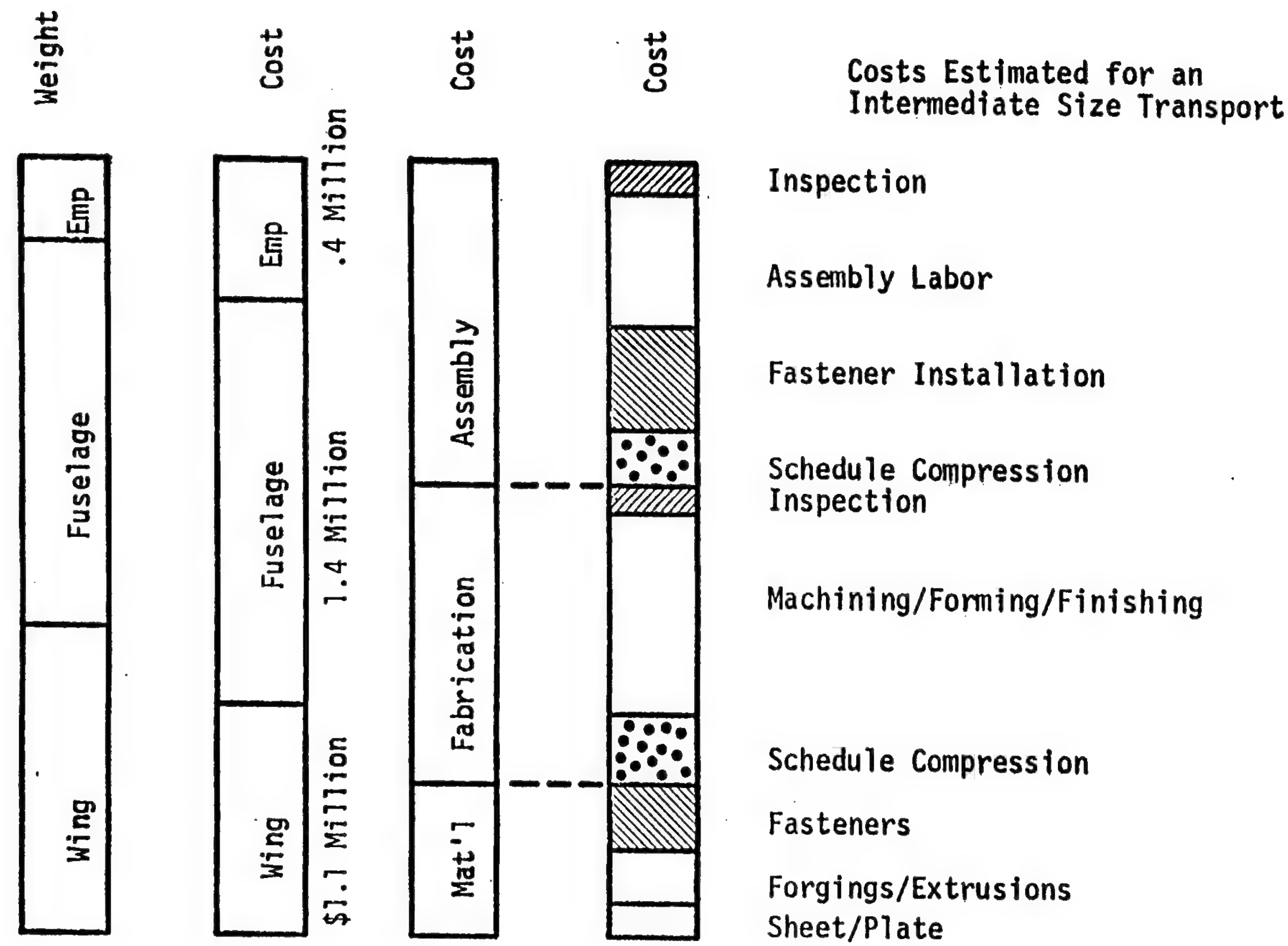
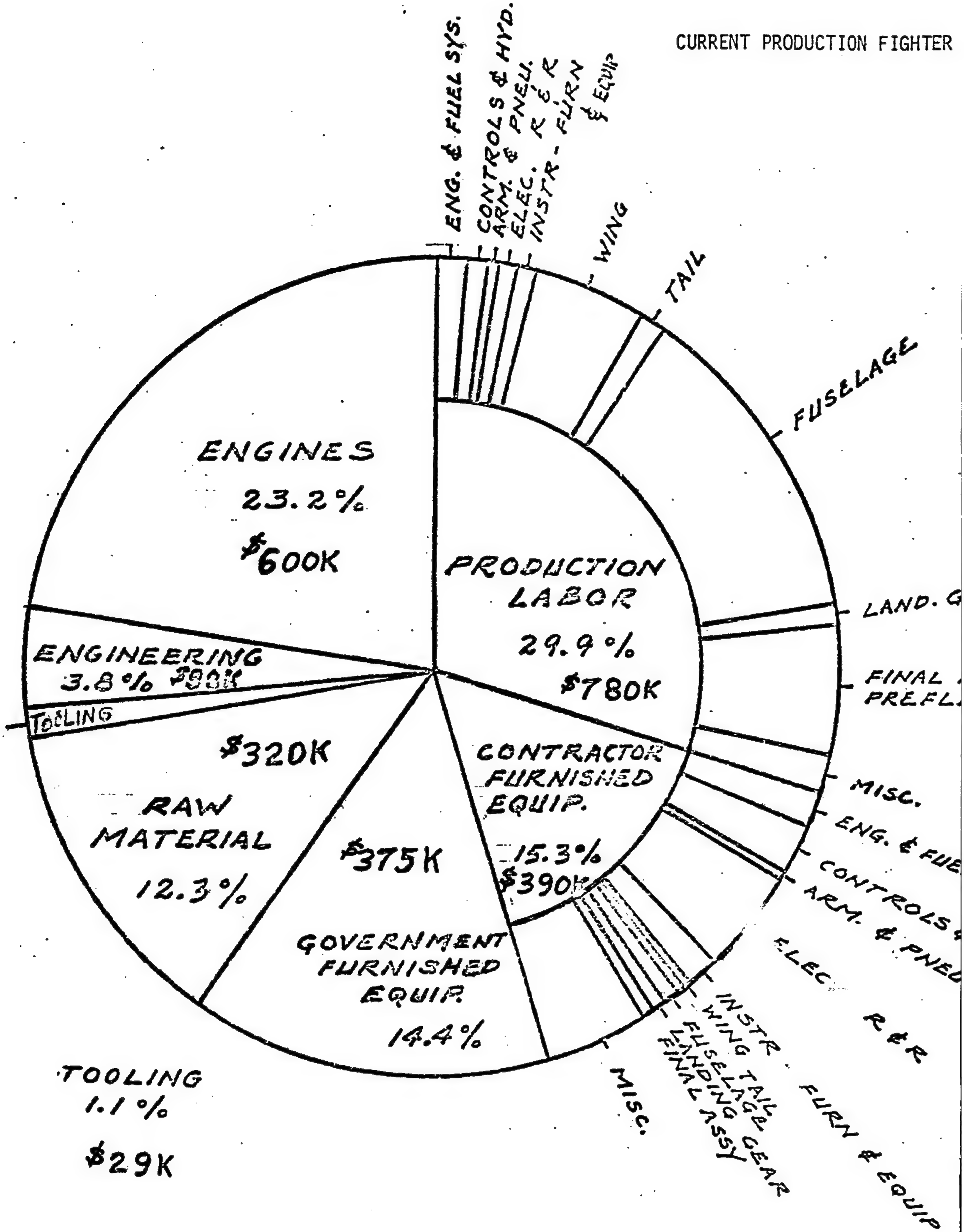


Figure B-13. Production Cost at 1000th Airplane



Production labor	29.9%
Engines	23.2%
Contractor furnished equipment	15.3%
Government furnished equipment	14.4%
Raw material	12.3%
Engineering	3.8%
Tooling	1.1%
	100%

This breakdown shows that approximately 30% of the production cost is accounted for by the labor required to produce the primary structure, and is the area of concern to which efforts to reduce costs were applied.

Additional perspective can be obtained in the area of primary structure of supersonic fighter type aircraft by considering the structural weight and cost of major assemblies as a percentage of total structural weight and cost. A chart showing these percentages is presented in Figure B.14.

This chart shows that although the inner wing is approximately 1/3 of the total structural weight, its cost is less than 1/4 of the total structural cost. This is due principally to the use of unitized design having a minimal number of parts and fasteners.

By contrast, the forward fuselage, with less than 1/5 of the total structural weight represents 1/4 of the total structural cost. This is accounted for by the extra complexity introduced by the use of numerous "bits and pieces" and the multiplicity of fasteners required for their attachment. This tends to follow the same pattern as for transport type aircraft.

Another factor to consider is the favorable impact of production quantities in driving costs down, as illustrated in Figure B.15. Values of "actual fabrication manhours/lb. of structural weight" vs. "number of

Figure B.14 Structural Weight & Cost of Major Assemblies of Fighter Aircraft as a Percentage of Total Structural Weight & Cost.

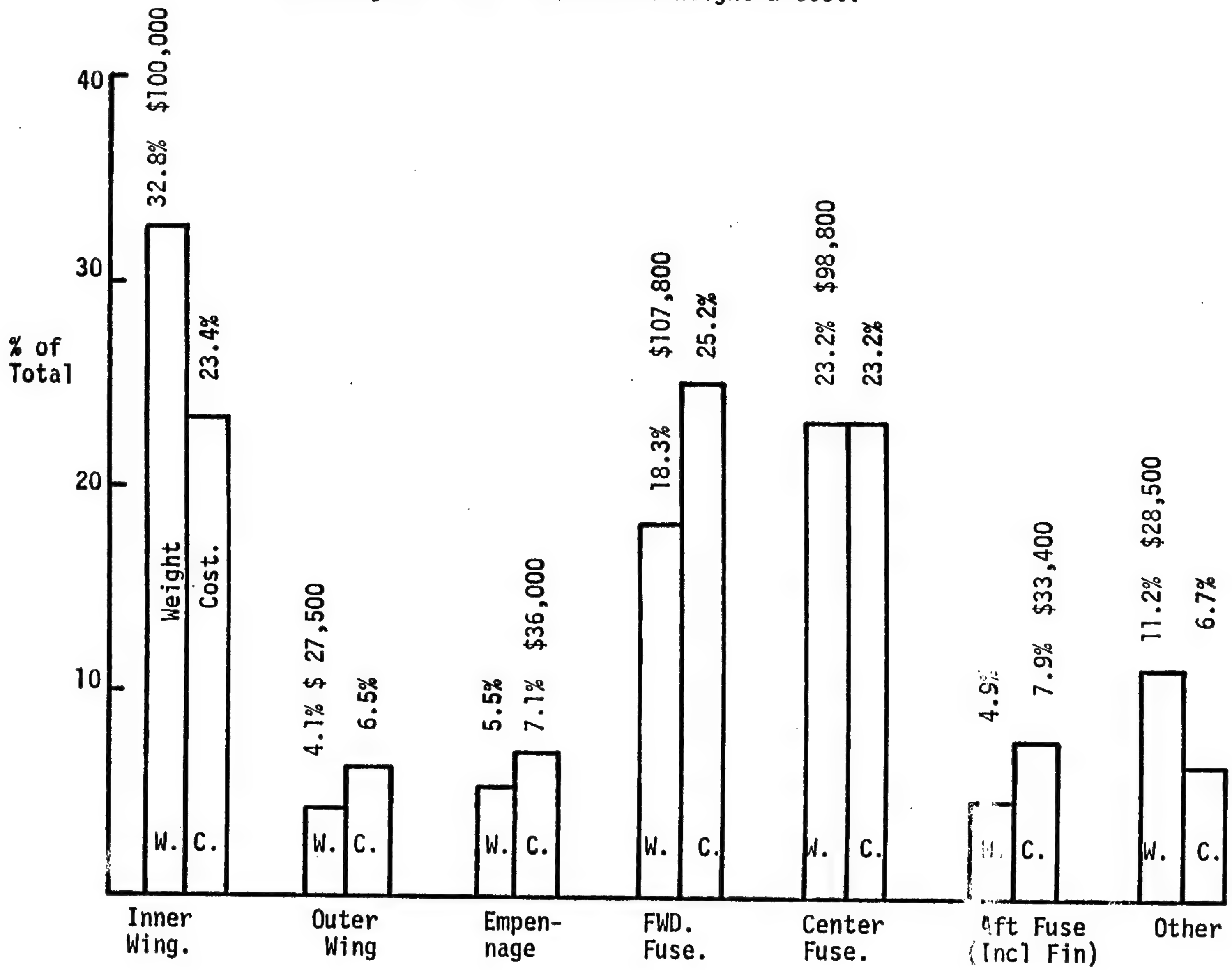
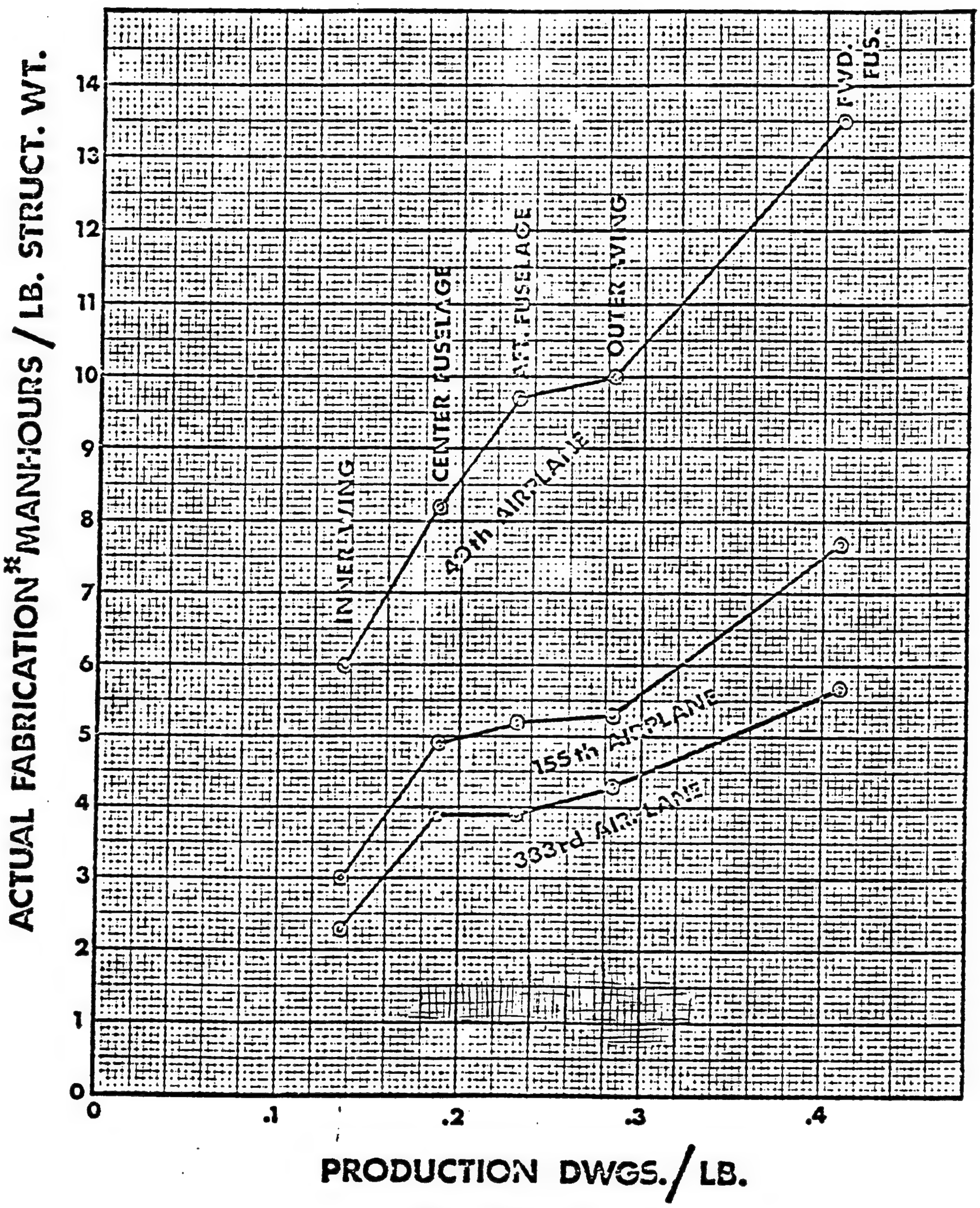


Figure B.15 Number of Drawings Vs. Fabrication Man-Hours



*INCLUDES STRUCTURAL FABRICATION, ASSEMBLY & INSTALLATION LABOR.

production drawings/lb. of structural weight" shows that for the inner wing at a value of approximately .14 for "number of production drawings/lb. of structural weight" the "actual fabrication manhours/lb. of structural weight" at the 333rd airplane was approximately 42% of that at the 40th airplane. The fewer number of production drawings per lb. of structural weight for the wing vs. the forward fuselage i.e., .14 vs. 41 is a measure of the higher use of unitized design in the wing.

II. AIRFRAME MATERIALS

The predominant materials used in airframe construction are aluminum and titanium. In subsonic aircraft, aluminum represents 90% to 95% of the airframe, while in MACH 2 class supersonic aircraft aluminum drops to 70% with titanium increasing to nearly 30%. For the MACH 2.6 to 3.0 class, titanium becomes the major structural material.

These two materials share several common cost problems in relation to airframe construction:

1. Poor utilization of material which is aggravated by increasing raw material cost.

2. Costly when assembled as small parts into larger structures using a large number of fasteners.

3. Lack of confidence in some sectors of the industry, in joining technologies which could provide larger economic components.

The unique problems associated with these materials and product forms are described further in the following paragraphs.

A. Aluminum in Primary Structures

In subsonic airframes, aluminum represents about 8% of the total cost, while in supersonic airframes it represents about 6.5%. About 205 million pounds of aluminum will be consumed in 1972 by general, commercial and military aircraft in the form of sheet, plate, extrusions and forging. Additional quantities will be used in the form of castings, bar and rivets but they will not be treated in this outline.

A look at the major product forms reveals a rather uniform distribution by weight but the value is highly biased toward the custom or engineered product forms such as extrusions and forgings (see Table B.II). The data indicates that although sheet and plate constitute over 50% of the weight of aluminum used in aircraft construction, they account for only 36% of the cost. Forgings are the largest cost aluminum product form used by the aircraft industry. Formings also require a high percentage of fabrication in relation to raw material used. This fact indicates that the aircraft manufacturers have found it cost effective to pay a higher unit cost for a product that is made closer to finish form even though the product has a higher fabrication requirement and often involves considerable tooling expense (see Table B.II). This suggests that it is generally cost effective to produce a product as near net as technology and finished design requirements will allow. The advent of improved machining techniques such as direct numerical control (DNC) have changed some of the tradeoff considerations, but it is still true that a great deal of excess metal can be removed by the raw material supplier more efficiently than by machining. Because of low cost of aluminum

TABLE B.II ALUMINUM PRODUCT FORMS AND DISTRIBUTION

(a) Use Profile - All U.S.

PRODUCT	% of Total	
	Weight	Value
SHEET	26%	19%
PLATE	31	17
EXTRUSIONS	20	30
FORGINGS	83	34
	100%	100%

(b) Cost Distribution

PRODUCT	Cost Element		
	New Mtl	Melting	Fabrication
SHEET	26%	3%	71%
PLATE	38	3	59
EXTRUSION	13	2	85
FORGINGS	14	2	84

raw material in relation to a finished product such as forgings (see Table B.III) it appears that the most cost effective situations will occur either when the material supplier can provide a product which needs little or no machining or further fabrication before assembly or when a minimal tooling/maximum definition product can be obtained. As shown in Figure B.17, conventional forgings in the 14% to 30% recovery range are cost effective in the 500 to 2000 in^2 plan view area category. Similarly, net or precision forgings are cost effective in the under 500 in^2 area provided the recovery is at least 90% or better and volume is sufficient to cover tooling.

Aluminum plate continues to be used in large quantities because of its low unit cost, large sizes, lack of tooling costs and ease of inspection. When coupled with the improved machining techniques now available, it often proves better to machine large planform, relatively thin parts, from plate rather than forgings. Long wing skins and planks are typical examples.

Probably the most cost effective material on a modern airplane is the sheet used for the skin. Material recovery is often as high as 85%, and when coupled with the low unit cost, makes it difficult to supplant.

Extrusions provide contour in only two dimensions, except in special situations where stepped shapes are used to reduce input weight. Here again the cost of leaving the metal at the mill is less than removing it at the aircraft manufacturers plant.

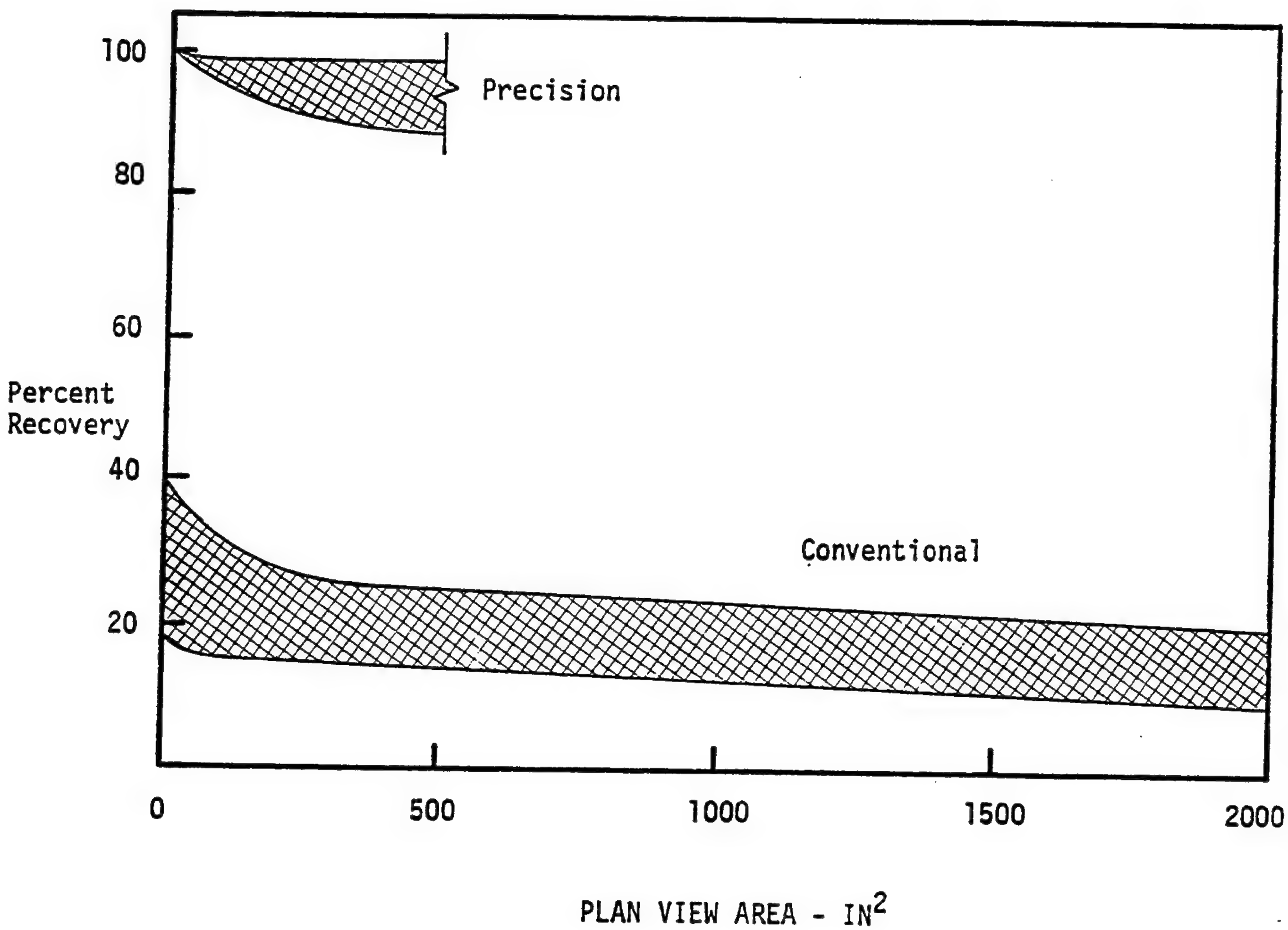
TABLE B.III ALUMINUM FORGINGS *

Typical Cost Distribution

COST ELEMENT	% of Total
Material **	25%
Forging	30
Processing	35
Inspection & Cert.	10
	100%

* Conventional Draft
** Composite of ingot and stock

Figure B.17 Forging Recovery



B. Titanium in Primary Structures

The high cost of titanium (per product form) is still given as a major deterrent to its more extensive use in airframe components. This is true even in view of the fact that since the early 1950's, the composite price index has decreased 5 fold. This decrease in composite price index to about $3.50/lb has come about through increased volume in the last 20 years, accompanied by improvements in rpoductivity and equipment. One procedure which has remained, however, is the Kroll process for making sponge. As can be seen from Table B.IV the cost of sponge, made by the batch type Kroll process, remains a significant portion of the base selling price of both billet and plate. As shown in Table B.V, it is estimated that the use of an electrolytic process for making sponge could reduce its cost by up to 20%, for a plant producing 15,000 tons/year.

Further reductions in the final part cost of titanium are possible through more efficient use of specific mill products and an increase in the volume sales of mill products. Table B.VI shows that for the typical titanium wing plank for a supersonic airframe, the 5:1 utilization ratio after machining has increased the overall base material cost from about 8% to 40%. Improvements in machining techniques, and/or new methods of plate fabrication, such as rolling tapered and/or ribbed plate, are needed. Typical Titanium Sheet Prices are shown in Table B.VII.

At present, the titanium industry is operating at 40% capacity. under these circumstances, each operating production unit must defray a disproportionate amount of the costs of carrying the entire capital

TABLE BIV. Ti-6Al-4V Plate & Billet (Distribution Cost)

Basic Element	Percent of Total Cost	
	Billet	Plate
1. Total Input Material, Incl. Electrode Preparation		
A) Sponge	42%	26%
B) Master Alloy	11%	7%
C) Revert	5%	3%
	58%	36%
2. Double Vacuum Consumable Melt and Testing	7%	5%
3. Total Conversion, Forge and/or Roll, Condition & Test	35%	59%
Totals	100%	100%
Product Base Book Price - No Extras Appl.	\$2.25/lb	\$3.60/lb

*Confirming Reference "Report on Ti - The ninth Industrial Meeting" - S.C. Will

TABLE B.V Ti SPONGE BREAKDOWN

Basic Element	Percent of Total Cost *		
	Kroll & Leach	Kroll & Distilled	Electrolytic (Estimates)
1. Ore (6 1/2¢/LB) and Raw Materials (Mg,Cl,C) **	26	Same	Down
2. Power and Utilities	9	Same	Same
3. Equipment and Supplies (Depreciation & Taxes)	25	up	up
4. Labor	35	up	Down
5. Cost of Capital	5	Same	Same
Totals	100%	----	Less by 10

*Confirming Reference: "Report on Titanium - The Ninth Industrial Metal" Samuel C. Williams

** Primary Ore Rutile (95% TiO_2); 1 LB containes 0.57LB Titanium

TABLE B.VI TYPICAL TITANIUM WING SKIN
Cost distribution

Element	Percent of Total Cost
1. Total Input to Ingot	15%
2. Melting	2%
3. Conversion to Plate	24%
4. Machining	39%
5. Forming	6%
6. Trimming	4%
7. Drilling	10%
	100%

* Starting Plate Weight: 1450 LBs
Finish Plate Weight: 280 Lbs

TABLE B.VII TYPICAL TITANIUM SHEET PRICES

Gage Size	Price per Pound		
	Ti-6Al-4V Milt 9046-6	Ti8Mo-8V2Fe 3AL TiMet Inter.	Ti-65A Milt 9046-6
0.020"	$15.60	$8.10	$6.75
0.040"	10.30	6.90	5.55
0.060"	8.75	6.60	5.40
0.100"	7.95	6.40	5.20

* Book One Price - No. Quantity
Extra Applied; (36" wide x 96" long)

investment. At full capacity of mill product resulting from 85×10^6 ingot lbs/year, the titanium industry could realize cost reductions through greater distribution of depreciation and overhead charges.

Recommended items that could lead to titanium cost reduction are summarized as follows:

1. Standardize on specifications, stock sizes and inspection requirements.

2. Don't "over-engineer" the technical requirements (i.e., excessive acceptance testing, be careful to call out only NDT requirements necessary to assure mill product of acceptable quality).

3. Establish reasonable guidelines for the use of potentially discrepant elements and parts (i.e., How bad are the borides?; Can the part really live with that small sonic indication, whatever it might be?).

4. Use lower cost alloys (i.e. Beta alloys).

These recommendations are discussed further in Section VI of this Panel Report.

III. PART PROCESSING

A. Titanium and Steel Forging

An analysis was made of forging cost distribution which include key areas from assembly and installation of the finish machined part into the primary airframe structure back through the forging and mill manufacture to include input materials into the ingot melting process.

Forging cost analysis was done in broad terms using several examples of parts having range of plan areas in order to identify a general pattern. Table BVIII presents these results for titanium forgings with about 50 to 1500 in^2 in plan area. About 75-80% of the billet stock put into the forging process is shipped to the airframe manufacturer. Contributing to the poor metal utilization are losses resulting from open die forging of the square or round billets into prepared shapes for initial closed die operations. The configuration of the prepared shape is sufficiently approximate to often promote irregular and excessive flash loss and non-uniform metallurgical characteristics.

Cost distribution for the parts studied is expressed as percentage of forging cost exclusive of cost of tools and dies. The latter is widely recognized to be a high cost, and often a long lead-time item. As shown in Table B.VIII the approximate cost distribution is as follows:

1. Forging stock (Material) represents 40-50% of titanium forging cost.

2. Actual metal deformation (Forging) accounts for about 20-30%.

3. Other manufacturing operations necessary to produce a forging (processing) is about 10-20%. This includes heat treat, cleaning, grinding, etc.

4. Non-manufacturing costs required to comply with quality and contract demands (Compliance) represents 10-20%. This includes inspection, testing, engineering, certification, etc.

A similar analysis is shown in Table B.IX for two alloy steel parts; one air melt (Electronic Furnace) and one vacuum arc remelt (VAR).

TABLE B.VIII - APPROX. COST DISTRIBUTIONS FOR MANUFACTURE OF SEVERAL TITANIUM FORGINGS

	Alloy					
	6-6.2	6-4	6-4	6-4	6-4	Ti
Plan Area (Sq.In)	50	150	750	1250	1500	500/1500
Gross Wt (LB.)	28	47	185	500	1175	
Frgd. Wt. (LB)	21	40	125	385	950	
Cost Distribution (%)						
Material	45	44	41	43	45	50
Forging	24	20	31	30	23	18
Processing *	17	14	10	14	16	20
Compliance **	14	22	17	11	16	10
Forger Machining	-	-	1	2	-	-

* Non-Forging Mfg. Costs, (e.g. cleaning, etc)

** Non-Mfg. Costs Required to Comply with Quality & with Contract (e.g. Insp., Test, Engrg, etc.)

TABLE B.IX - COST DISTRIBUTION FOR MANUFACTURE OF 2 STEEL FORGINGS

	PROCESS	
	EF	VAR
Plan Area (SQ.IN)	2000	3000
Gross Wt. (LB)	1750	6000
Forged Wt. (LB)	-	5200
Cost Distribution (%)		
Material	32	40
Forging	24	30
Processing *	17	18
Compliance **	18	10
Forger Machining	9	2

*Non-Forging Mfg. Costs, (e.g. Cleaning, Heat-Treat, etc)

**Non-Mfg. Costs Required to Comply with Quality & with Contract (e.g. insp., test, engrg, etc)

Several specific examples of titanium forgings are described in the following paragraphs. These examples show the percent of final machined or final machined-assembled - installed costs broken down into key areas traced back to input melting ingredients. Cost data tabulations and example illustrations are included in support of the discussion.

Figure B.18 shows a breakdown of the cost of a finished titanium spar from the point of input material required by the forging supplier to the final machining by the fabricator. This shows the cost savings in conventional over blocker forging design where quantity and time schedule permits (as was discussed earlier).

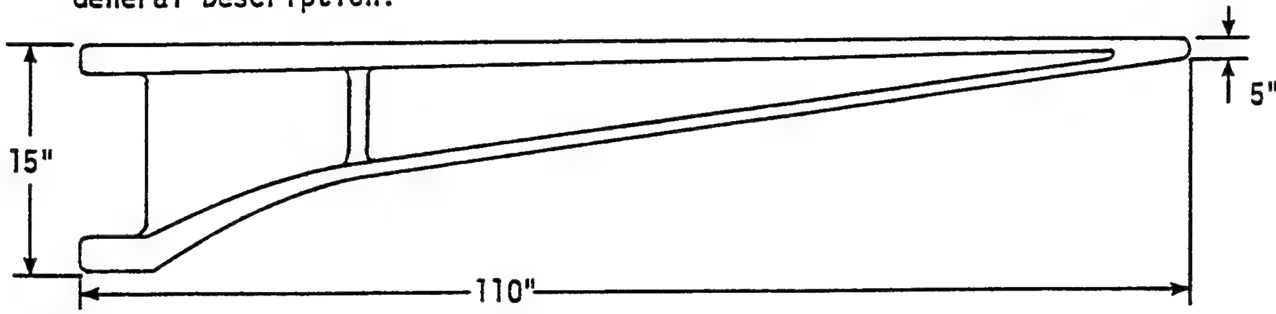
The exceedingly poor material utilization resulting from the use of blocker forgings is dramatically demonstrated by this actual example which shows a ratio of forging weight to machining weight of 23 (i.e., after final machining, only 48 lb. remains of the original forging weight of 1100 lbs). Although still far from ideal, a comparison of a 5° die forging to the blocker forging shows a significant reduction in the ratio of forging weight to final machining weight (i.e., from 23 for the blocker down to 12 for the 5° die forging).

While the breakdown of finished part cost between total forging cost and final machining is approximately the same (1/3 and 2/3) for both the blocker and the 5° die forging, the cost of a finished part machined from the 5° die forging is approximately 70% of one made from a blocker.

Figure B.18

Titanium Wing Spar Forging Process Comparison

General Description:



	Blocker Forging	Conventional Forging
Approx. Plan Area, SQ. IN	1000	1050
Forging Weight, LB.	1100	580
Machined Weight, LB.	48	48
Ratio $\frac{\text{Forg. Wt.}}{\text{Mach. Wt.}}$	23	12
Approx. Cost Distribution: (Recurring)		
Input Material	9%	6%
Ingot Melting	1	1
Total Conversion	5	4
Total Forging Stock	15%	11%
Actual Forging	8	6
Forging Processing	5	4
Compliance	5	3
Forger Machining		
Total Forging Cost	33%	22%
Final Machining	67	46
Total	100%	70%

30% Reduction with Conventional over Blocker

This example illustrates the cost impact of two military weapons procurement problems: (1) the effect of compressed schedules wherein it is necessary to order long lead time components, with minimum tooling and without a refined design (billet or blocker forgings) to meet schedules, and (2) the high cost of procuring and removing the excess input material to obtain an efficient, low-weight, final component configuration.

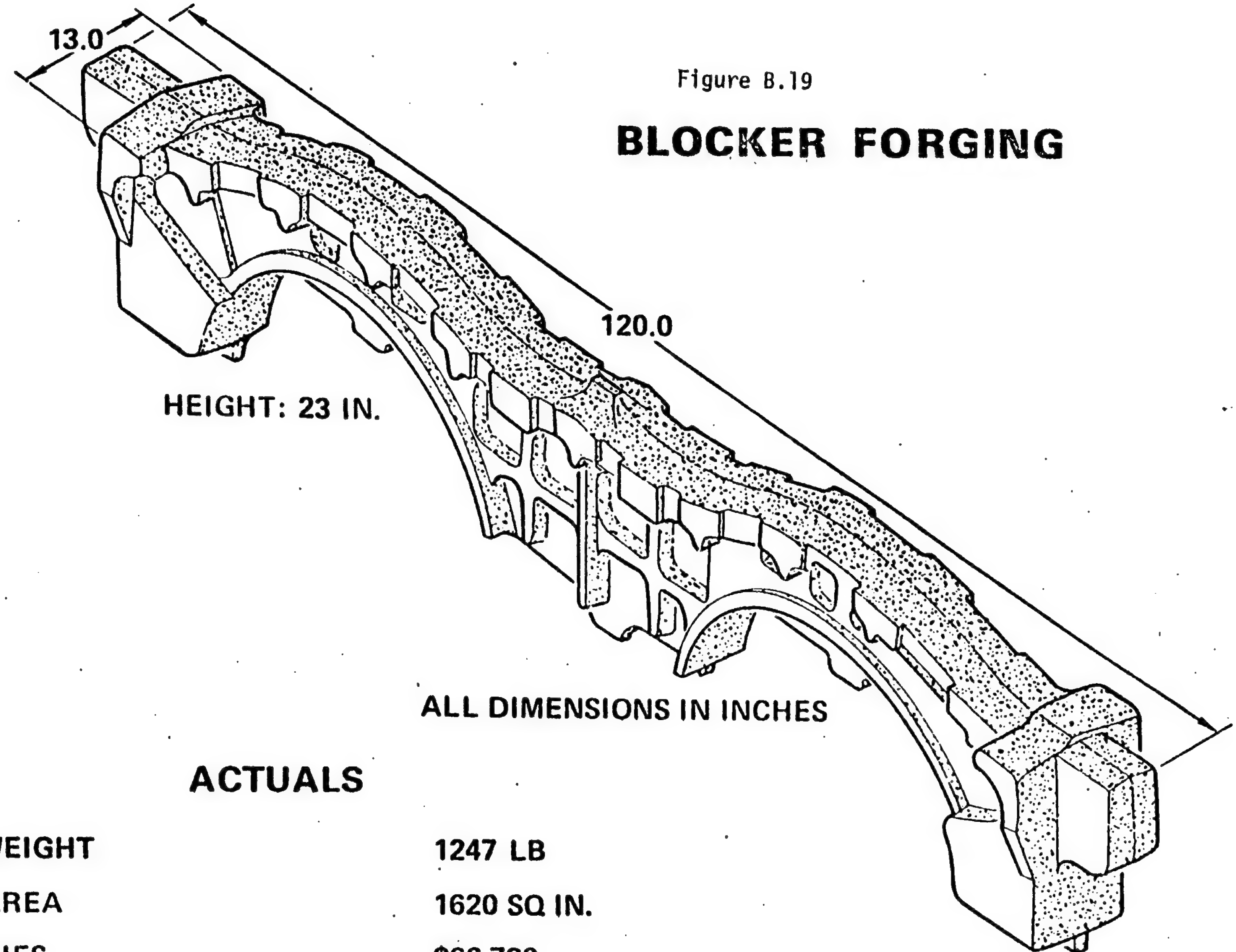
By reducing the weight of input material, savings accrue in both materials and machining costs with the savings in machining costs about double the material savings.

As another example, the cost distribution data for manufacture of the blocker forging in Figure B.19 is shown in Table B.X. A similar titanium bulkhead example, but larger in size, is shown in Table B.XI. As can be seen from these examples, trade-offs can be made between machining and forging costs. Other than final machining cost, the pattern reflects an accumulation of relatively small factors rather than major areas.

A cost comparison of forging methods for the titanium bulkhead shown in Figure B20 is presented in Table B.XII. This indicates that for this large finished titanium bulkhead, a finished part made from a 5° die forging is more cost effective than one made from either a blocker forging (Figure B.19) or a reduced volume isothermal forging (Figure B.21) (A net isothermal forging is not attainable at this time). In this particular case, the blocker was 11% and the gross isothermal 26% more costly than the 5° die forging. In the case of the blocker, while the forging die was less expensive, the machining, tooling and forging costs were higher;

Figure B.19

BLOCKER FORGING



ACTUALS

WEIGHT	1247 LB
AREA	1620 SQ IN.
DIES	$66,730
FORGING COST EACH	$7,494

UPPER FUSELAGE BULKHEAD
STATION 626.9
PART NUMBER 68A324116

Table B.X

Titanium Bulkhead - Blocker Forging

General Description:	Blocker Forging
Approx. Plan Area, SQ.IN.	1600
Forging Weight, LB	1250
Machined Weight, LB	75
Ratio $\frac{\text{Forg. WT.}}{\text{Mach. Wt.}}$	
Approx. Cost Distribution: (Recurring)	
Input Material	7%
Ingot Melting	1
Total Conversion	5
Total Forging Stock	13%
Actual Forging	7
Forging Processing	5
Compliance	5
Forger Machining	-
Total Forging Cost	30%
Final Machining	70
Total	100%

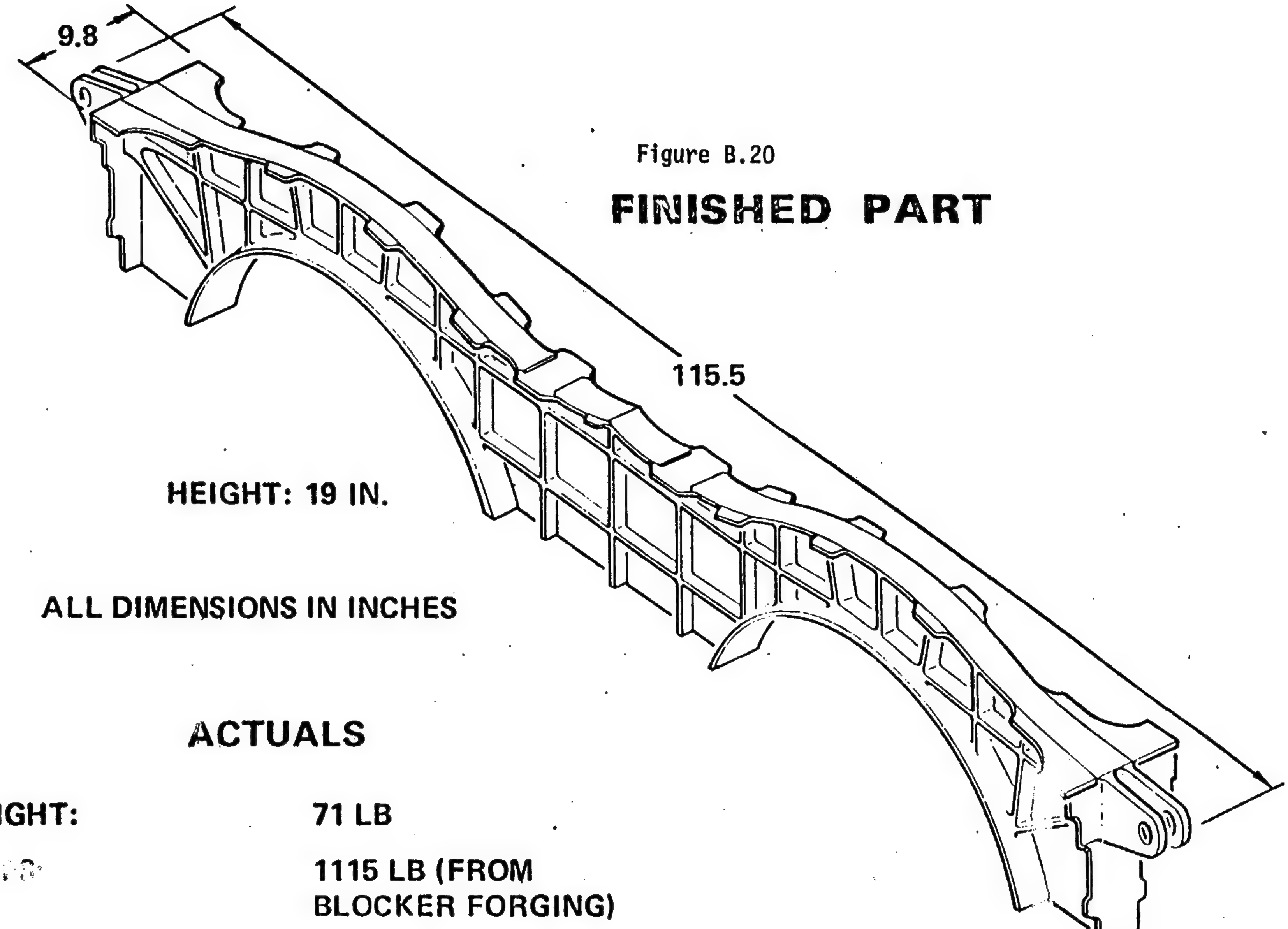
Table B.XI

Titanium Bulkhead - Blocker Forging

General Description:	Blocker Forging
Approx. Plan Area, SQ.IN.	2200
Forging Weight, LB.	2400
Machined Weight, LB.	125
Ratio $\frac{\text{Forg. WT}}{\text{Mach. WT}}$	19
Approx. Lost Distribution: (Recurring)	
Input Material	9%
Ingot Melting	1
Total Conversion	5
Total Forging Stock	15%
Actual Forging	9
Forging Processing	5
Compliance	5
Forger Machining	-
Total Forging Cost	35%
Final Machining	65
Total	100%

Figure B.20

FINISHED PART



HEIGHT: 19 IN.

ALL DIMENSIONS IN INCHES

ACTUALS

WEIGHT:	71 LB
CHIPS:	1115 LB (FROM BLOCKER FORGING)
MACHINING COST:	$5,313
MACHINING TOOLING COSTS:	$46,800

UPPER FUSELAGE BULKHEAD
STATION 626.9
PART NUMBER 68A324117

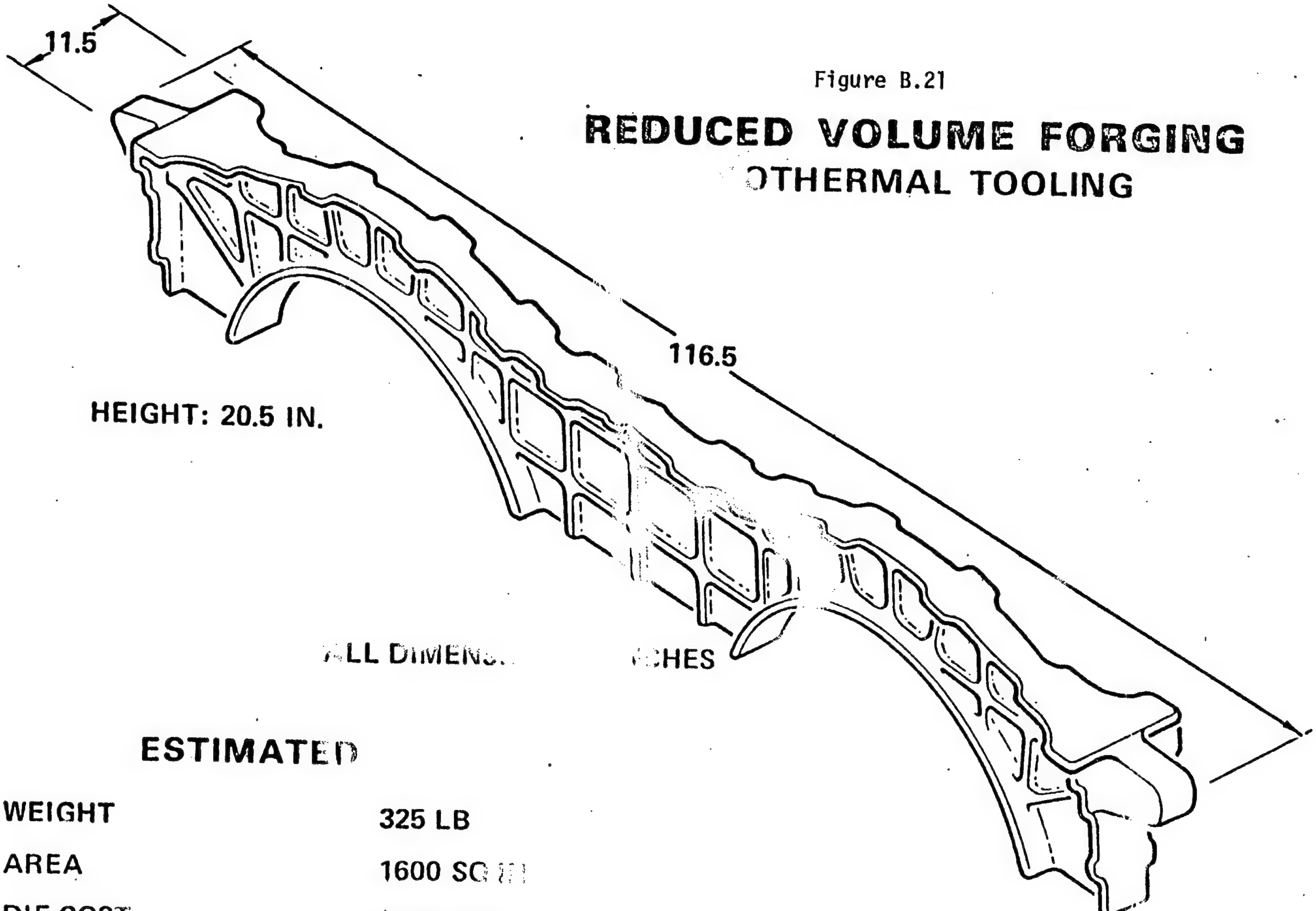
TABLE B-XII

TITANIUM BULKHEAD FORGING COST COMPARISON

	BLOCKER		5° DIE		GROSS ISOTHERMAL	
	lb.	% of Total 5°	lb.	% of Total 5°	lb.	% of Total 5°
Forging - Weight	1247	156	800	100	325	41
Finished - Weight	71	9	71	9	71	9
Metal Removed by Rough Machining	1115	139	668	83	193	24
Metal Removed by Finish Machining		8	61	8	61	8
Cost of Rough Machining		17		12		4
Cost of Finish Machining		17		17		17
Set-up, Load, Unload, QA		8		8		5
TOTAL MACHINING COST		42		37		26
Machine Tooling Cost (100 Parts)		4		3		3
Forging Cost		60		51		69
Forging Die Cost (100 Parts)		5		9		28
TOTAL COST		111		100		126
Cost - 5° as Base		+11		-		+26

Figure B.21

REDUCED VOLUME FORGING
ISOTHERMAL TOOLING



UPPER FUSELAGE BULKHEAD
STATION 626.9

ESTIMATED

WEIGHT	325 LB
AREA	1600 SQ [illegible]
DIE COST	$350,000
FORGING COST EACH	$8,694

TABLE B-XIII

5° DRAFT FORGING VS NET ISOTHERMAL FORGING

	5° DIE FORGING		NET ISOTHERMAL FORGING	
	LB	% of TOTAL	LB	% of TOTAL (5° Base)
Forging Weight - Lbs.	120	100	28	23
Machined Weight - Lbs.	18.6	16	18.6	15 (66)
Metal Removed by Rough Machining	94	78	6.7	6
Metal Removed by Finish Machining	7.4	6	2.7	2
Cost of Rough Machining		16		2
Cost of Finish Machining		15		5
Set-up, Load, Unload, QA, etc.		8		3
TOTAL MACHINING COST		39		10
Machine Tooling Cost (100 parts)		4		2
Forging Cost		51		35
Forging Die Cost (100 parts)		6		21
TOTAL COST		100		68
Cost - 5° as base		-		32

while in the case of the gross isothermal, although the machining cost was less than the 5° die forging, the forging and forging die costs were both significantly higher.

While the foregoing example did not show a favorable cost comparison between a gross isothermal forging and a 5° die forging, an isothermal forging can be cost effective for certain configurations (notwithstanding the considerably higher die cost), especially in those cases where a net or nearly net isothermal forging is attainable. A comparison of the finished titanium part shown in Figure B.22 as a 5° die forging (Figure B.23) and as a net isothermal forging (Figure B.24) shows a 32% saving when produced as a net isothermal forging. The significantly reduced machining and forging costs achieved in the isothermal forging, more than offset the higher die cost.

Another example of titanium forging cost distribution is shown in Table B.XIV and represents a large part which is blocker forged and extensively machined.

B. Material Utilization

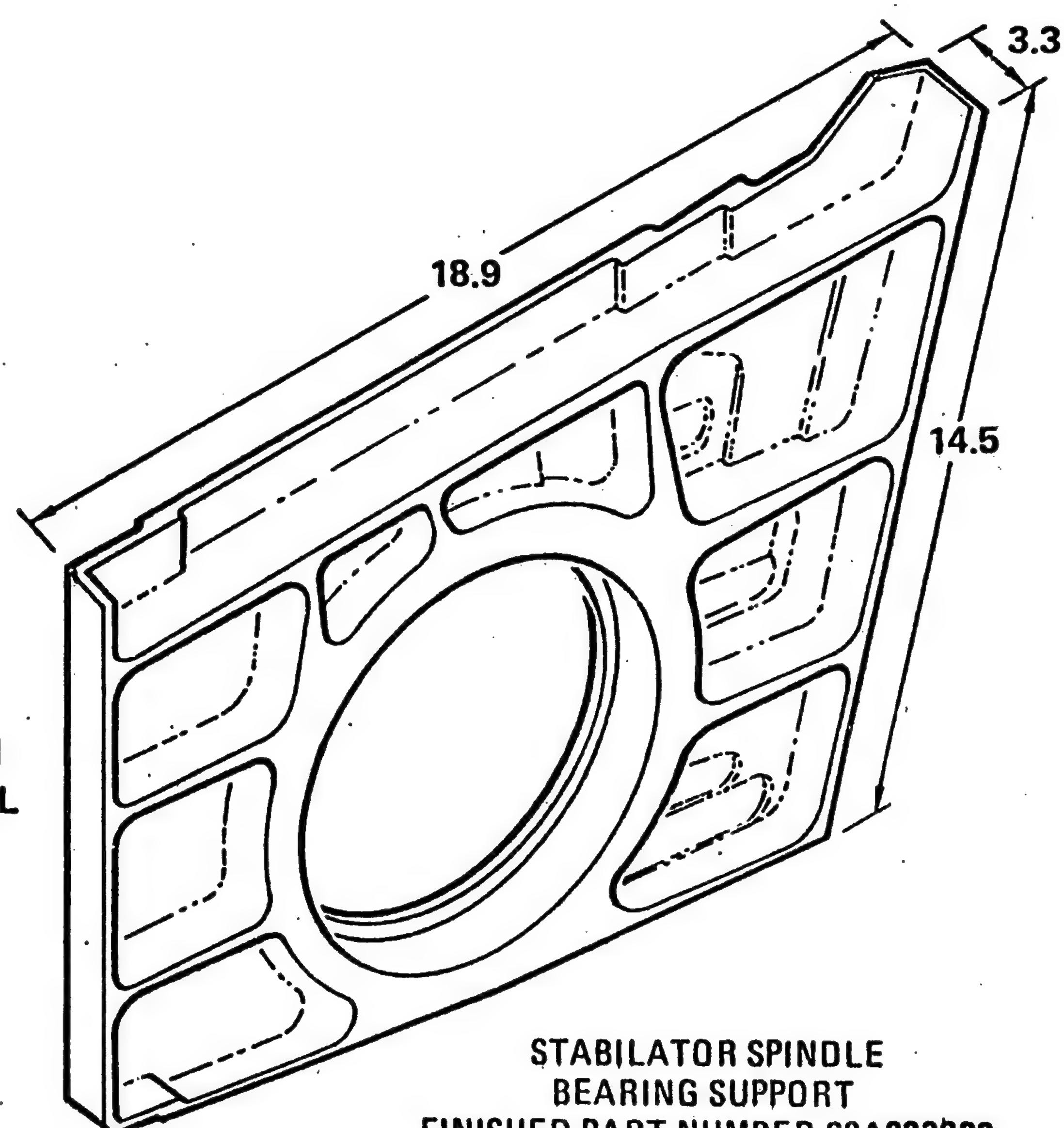
An important factor in determining the cost of finished part is material utilization which accounts for trim, offal, chips, overage, scrap, etc. Material utilization factors are applied to the finished weight of the various forms of material to obtain the procured weight. These factors are applied to convert from flyweight to buy weight. Table B.XV lists these material utilization factors that are applicable to highly sophisticated supersonic military fighters. These values are higher than utilization factors normally used for transport types of aircraft.

Figure B-22.

FINISHED PART

ACTUALS

WEIGHT:	18.6 LB
CHIPS:	101.4 LB (FROM CONVENTIONAL FORGING)
MACHINING COST:	$656
MACHINING TOOLING COSTS:	$6,500



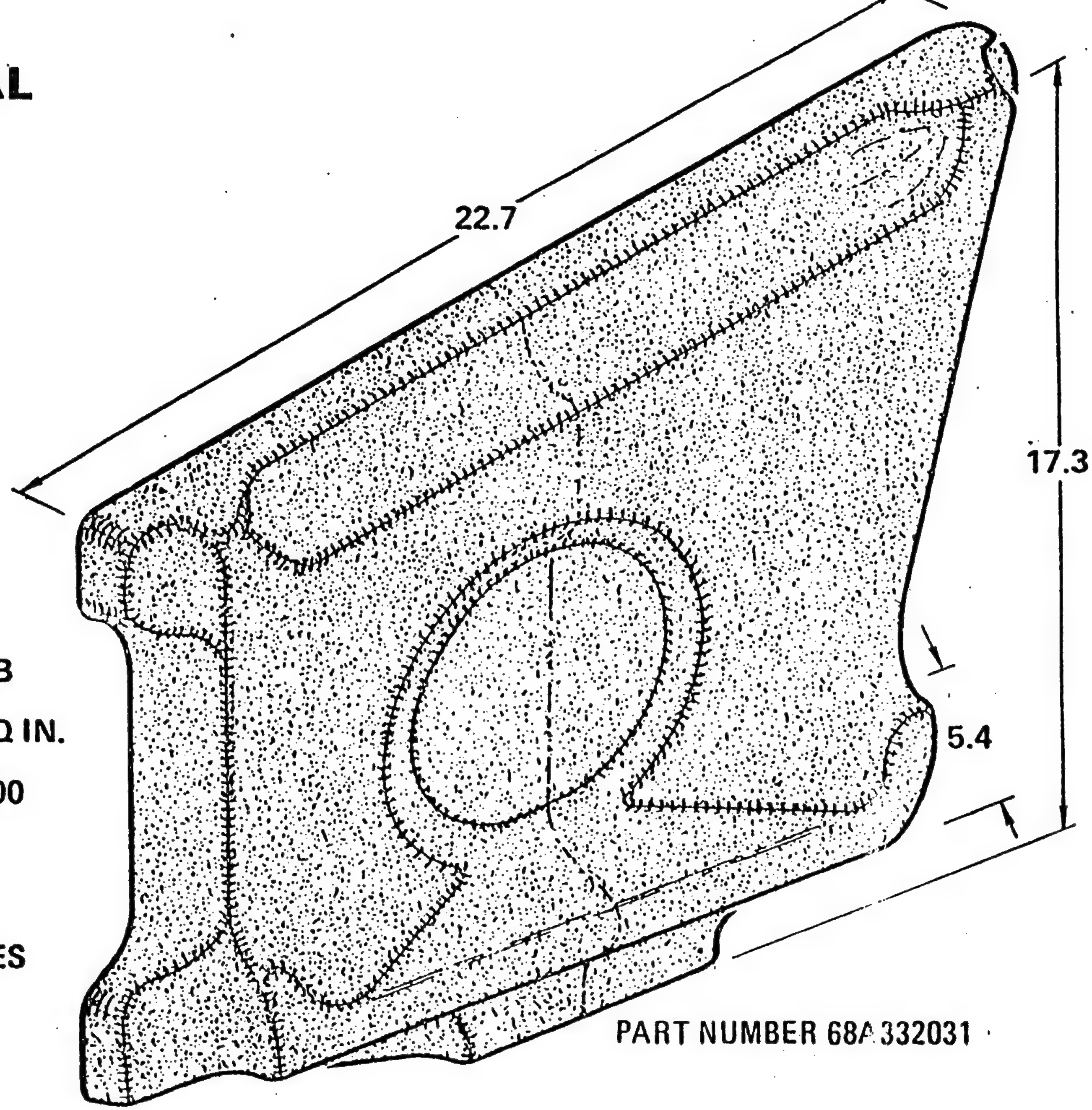
STABILATOR SPINDLE
BEARING SUPPORT
FINISHED PART NUMBER 68A332032

ALL DIMENSIONS IN INCHES

Figure B-23.

CONVENTIONAL FORGING

5° DRAFT



ACTUALS

WEIGHT:	120 LB
AREA:	307 SQ IN.
DIES:	$10,800
FORGING COST EACH:	$853

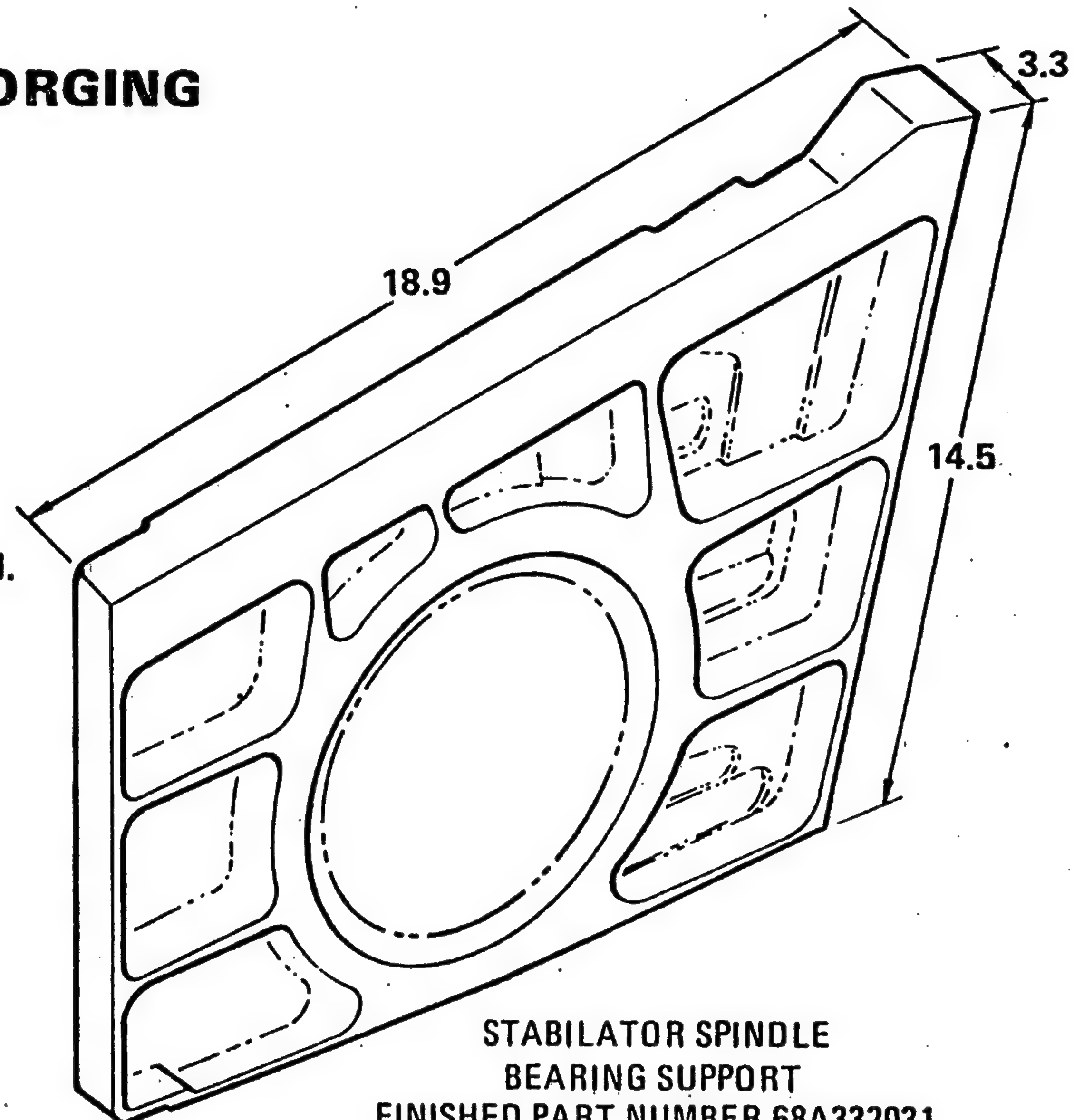
ALL DIMENSIONS IN INCHES

Figure B-24.

NET ISOTHERMAL FORGING

ESTIMATED

WEIGHT:	28 LB
AREA:	300 SQ IN.
FINISH WEIGHT:	18.6 LB
CHIPS:	9.4 LB
DIE COST:	$35,000
FORGING COST EACH:	$599
MACHINING COST:	$166
COMPLETED COST:	$1150



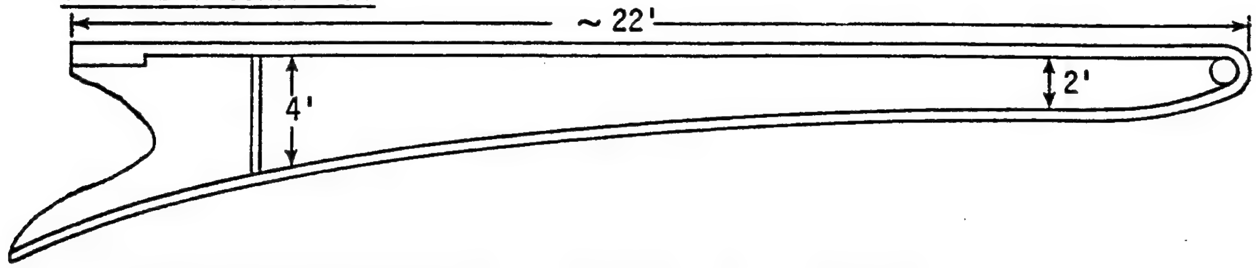
STABILATOR SPINDLE
BEARING SUPPORT
FINISHED PART NUMBER 68A332031

ALL DIMENSIONS IN INCHES

TABLE B-XIV

TITANIUM LANDING GEAR SUPPORT BEAM

GENERAL DESCRIPTION:



Approx. Plan Area, sq. in.	6000
Forging Weight, lb.	4000
Machined Weight, lb.	820
Ratio (Forg. wt./Mach. wt.)	4.9
Approx. Cost Distribution: (Recurring)	
Input Material	14%
Ingot Melting	2
Total Conversion	9
Total Forging Stock	25%
Actual Forging	14
Forging Processing	8
Compliance	8
Forger Machining	-
Total Forging Cost	55%
Final Machining	25
Assembly/Installation	20
TOTAL	100%

Table B.XV - Material Utilization Factors

Material Form	Material Utilization Factor
Formed Sheet and Plate	2.0 - 2.2
Chem Milled Sheet and Plate	2.5 - 2.8
Machined Plate	4.0 - 7.0
Machined Bar and Rod	4.0 - 5.0
Machined Forgings*	4.5 - 12.0

* Blocker Forgings run from 8.0 to 12.0
5° Die Forgings run from 4.5 to 8.0
Pressings run from 1.2 to 1.8
Titanium forgings run approximately 1.0 over that for aluminum

This results from the fact that military fighters, configured to optimum aerodynamic considerations, have a minimum of the geometrical elements considered desirable from a producibility viewpoint (i.e., straight line elements, circular cross sections, constant cross sections, etc.).

Another contributing factor results from the few numbers of duplicate parts ordinarily found in fighter type aircraft resulting from the need to save weight. Design efforts to modify nearly similar parts to a common configuration invariably add weight which cannot be tolerated.

The use of advanced type materials whose fabrication techniques are still being refined also call for higher material utilization factors than required for materials for which fabrication techniques are well documents.

Raw material cost for machined forgings are highly influenced by material utilization as shown in Figure B.25. The curves for various materials indicate the level of utilization required to be cost competitive in airframes.

C. Metal Removal

To develop a cost for metal removal, there are several factors to be considered, primary of these is material. These factors are shown in Table B.XVI. All the conventional or typical materials used in aircraft production are listed. Corresponding to these materials is a listing of each material's machinability factor rating. This is a unitless number that describes the relative ability of that material to be machined compared to B-1112 free-cutting steel as 100%. This factor is also a measure of difficulty of machining each material.

Figure B.25 - Material Cost VS. Material Utilization

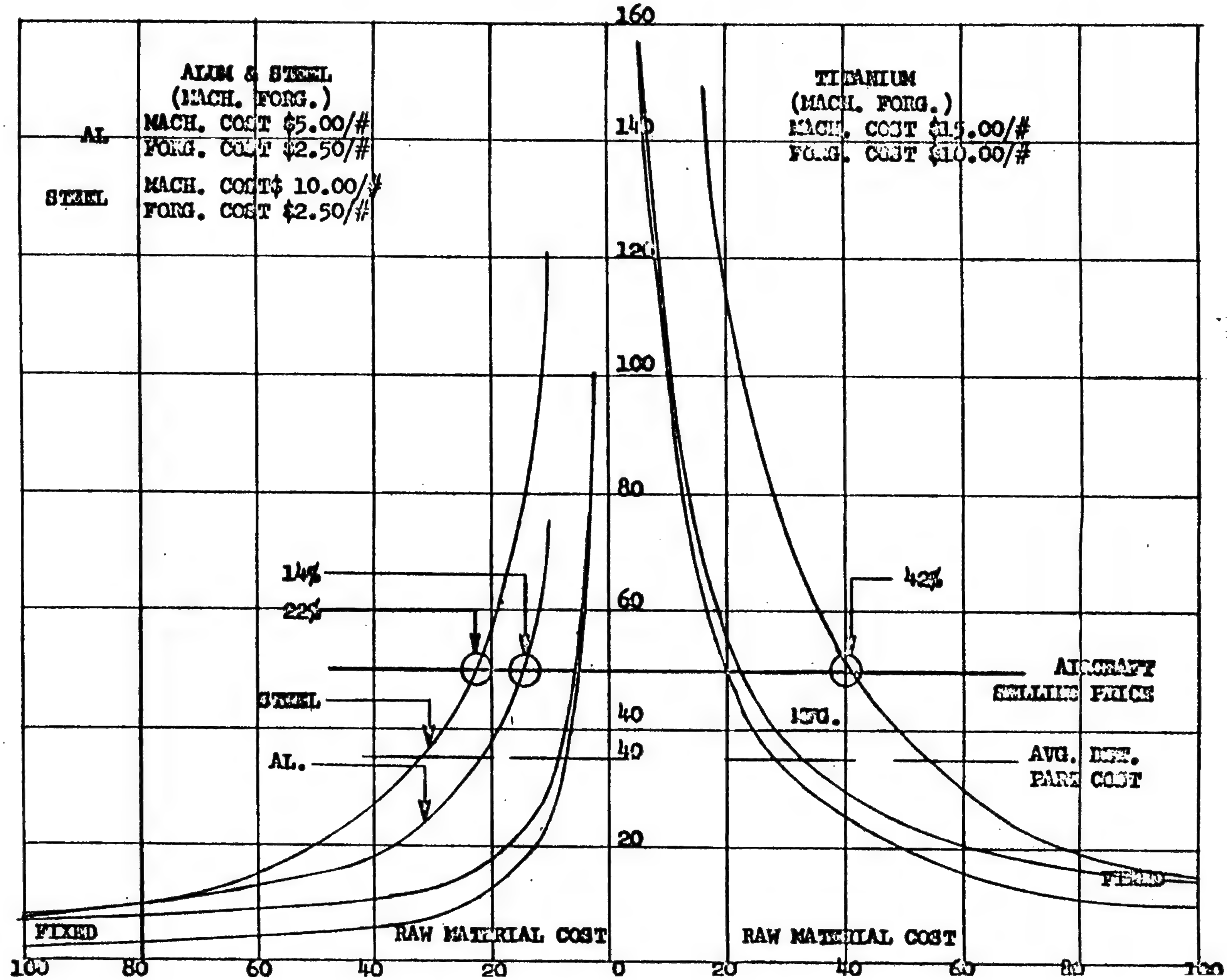


TABLE B-XVI

METAL REMOVAL MATERIAL FACTORS

MATERIAL	MACH. FACTOR	$ PER CUBIC INCH			
		SIMPLE	AVERAGE	COMPLEX	EXOTIC
MAG ALLOY	200	.05	.08	.12	.20
ALUM ALLOY	190	.07	.10	.15	.25
B1112 (STD)	100%	.20	.30	.45	—
303, 4130, 4135	65	.30	.45	.65	.75
4140, 8620	40	.35	.50	.75	1.00
4337, 4340	10	.40	.60	.90	1.20
302, 304, 316	50	.45	.65	1.00	1.20
321, MONEL, CPTi	45				
19-9, 1095	40	.50	.75	1.10	1.50
431, 17-7 PH	20	.60	.85	1.30	1.80
52100, 17-4 PH	25	.75	1.00	1.50	2.00
Ti ALLOY	25-30	1.00	1.50	2.25	2.[illegible]0

A spread is priced for each material in which the part or forging or extrusion to be machined is rated as simple, average, complex or exotic. Simple parts are those with straight lines, sides, etc. Average would represent parts like channels and tees. Complex would be those with contoured sections, cut-outs, pockets and contours. Exotic parts would be those with perhaps all the above plus compound contour and swarf or even undercuts that complicate metal removal.

To reflect quantity and its corresponding influence on machining cost a factor is used as shown in Table B.XVII. Thus, the cost of metal removal becomes: cost ($/Part) = $\left(\text{cu. in. to be removed}\right)\left(\frac{\$}{\text{cu.in}}\right)\left(\text{Q Factor}\right.$

In examining the cost of a finished part it is important to compare the cost of metal removal with "closer-to-final" shapes (i.e. forgings, etc.). Cost comparison factors for hog out vs. forging is shown in Table B.XVIII. For typical aircraft materials, such as aluminum (7075), 4130 steel, 17-4 stainless steel and Ti-6Al-4V, the cost of raw materials is estimated in cost/cu. in. The base material is aluminum and is shown as unity in all columns.

Die cost for forgings is compared for all materials in per units where forgings are used. Cost is based on a best effort or state-of-the-art part. Thin webs, small filled radii and tall thin flanges easy for aluminum will not generally be reproducible in the more difficult to forge materials. The result will be a slight increase to the part cost as shown in round numbers.

TABLE B-XVII

METAL REMOVAL QUANTITY FACTORS

QUANTITY	FACTOR
1 — 20	4.50
21 — 50	2.50
51 — 100	1.70
101 — 200	1.50
201 — 500	1.20
501 — 1,000	.90
1,001 — 2,000	.70
2,001 — 5,000	.60
5,001 — 10,000	.50
10,000 — UP	.40

APPROX COST $ PER PART = CU IN. X $\frac{\$}{\text{CU IN.}}$ X Q FACTOR

TABLE B-XVIII

HOG-OUT VS FORGING COST FACTORS

MATERIAL	COST/CU INCH	DIE COST	PART COST	TOOL COST	MACH COST
7075	1.00	1.00	1.00	1.00	1.00
4130	1.25	1.35	1.63	1.25	2.65
17-4	5.00	1.65	5.92	1.50	4.80
Ti	9.00	1.65	7.38	1.50	5.00

RELATIVE VALUE ALUMINUM IS BASE

	SPINDLES						EQUIPMENT TYPE		
	1	2	3	4	5	6	TRACER	TAPE (LO SPEED)	TAPE (HI SPEED)
YIELD	1.0	1.75	2.25	3.0	3.75	4.25	1.00	1.75	3.00

As materials become more difficult to machine, the cost to hold parts or provide tools increases as shown. The same becomes true for the machines that are necessary to perform these increases in metal removal requirements.

Yield of a conventional machine tool will increase obviously as the number of spindles increase but it is not a linear relationship due to the increase in setup costs.

Yield also increases where machine or equipment sophistication increases. This increase is compared to a Tracer machine. Lo-speed machines are a must for steel and titanium. Hi-speed machines are useful for metal removal of aluminum and magnesium.

D. <u>Diffusion Bonding of Titanium Structural Components</u>.

Diffusion bonding is a solid state joining process developed within the last ten years for fabrication of titanium structural components. Pieces of material cut from sheet, plate or bar are joined together within steel tools representing the configuration desired by heating the assemblies to 1700°F and applying a pressure of about 2000 pounds per square inch. Under these conditions the detail parts of the structure flow together to fill the void space within the die to conform to the configuration of the tools and simultaneously join together to become an integral one piece assembly. Material properties of diffusion bonded components may be superior to parts produced from bar, forgings and machining from a billet produced by die forging. This characterization is due to the fact that the elements making up a diffusion bond assembly are worked in the raw

material condition before machining of the required elements in depth to refine the grain size, texture the material in the direction of rolling, and improve mechanical properties including toughness characteristics. This must be determined by a test program for comparative properties of each method.

Diffusion bonded components show cost advantages over machining of equivalent parts from a forging when the plan view area of the part over 300 square inches and buy to fly ratios for forgings increase to 6-8-10/1 depending on plan view area. In addition, when rib height on a stiffened component increases above 2 inches, diffusion bonding shows an advantage. Lightweight parts are produced more cost effectively by diffusion bonding than by machining from plate or extrusions due to the improved material utilization inherent in the diffusion bonding process. The areas where the diffusion bonding shows cost reduction advantages over alternate methods are depicted in Figure B.26.

Cost trade studies for a typical wing cover where diffusion bonding is compared against an equivalent riveted structure are shown in Figure B.27. Not only is a cost advantage shown but also 33 pound weight savings. Another example is shown in Figure B.28 where main center box spars are compared against diffusion bonded and forged equivalents. Diffusion bonding showed a significant advantage due to the large plan view areas of the parts depicted and the depth of the pockets between the caps and stiffening rib sections.

Figure B.29 illustrates a current production part that is currently machined from titanium and is a possible candidate for diffusion bonding.

Figure B.26 - Diffusion Bonding - Lower Cost

- LARGE AREA
- DEEP POCKETS
- THIN GAGE STRUCTURE
- MINIMUM FINISH MACHINING
- IMPROVED MATERIAL UTILIZATION
- DESIGN TO DELIVERY TIME MINIMIZED

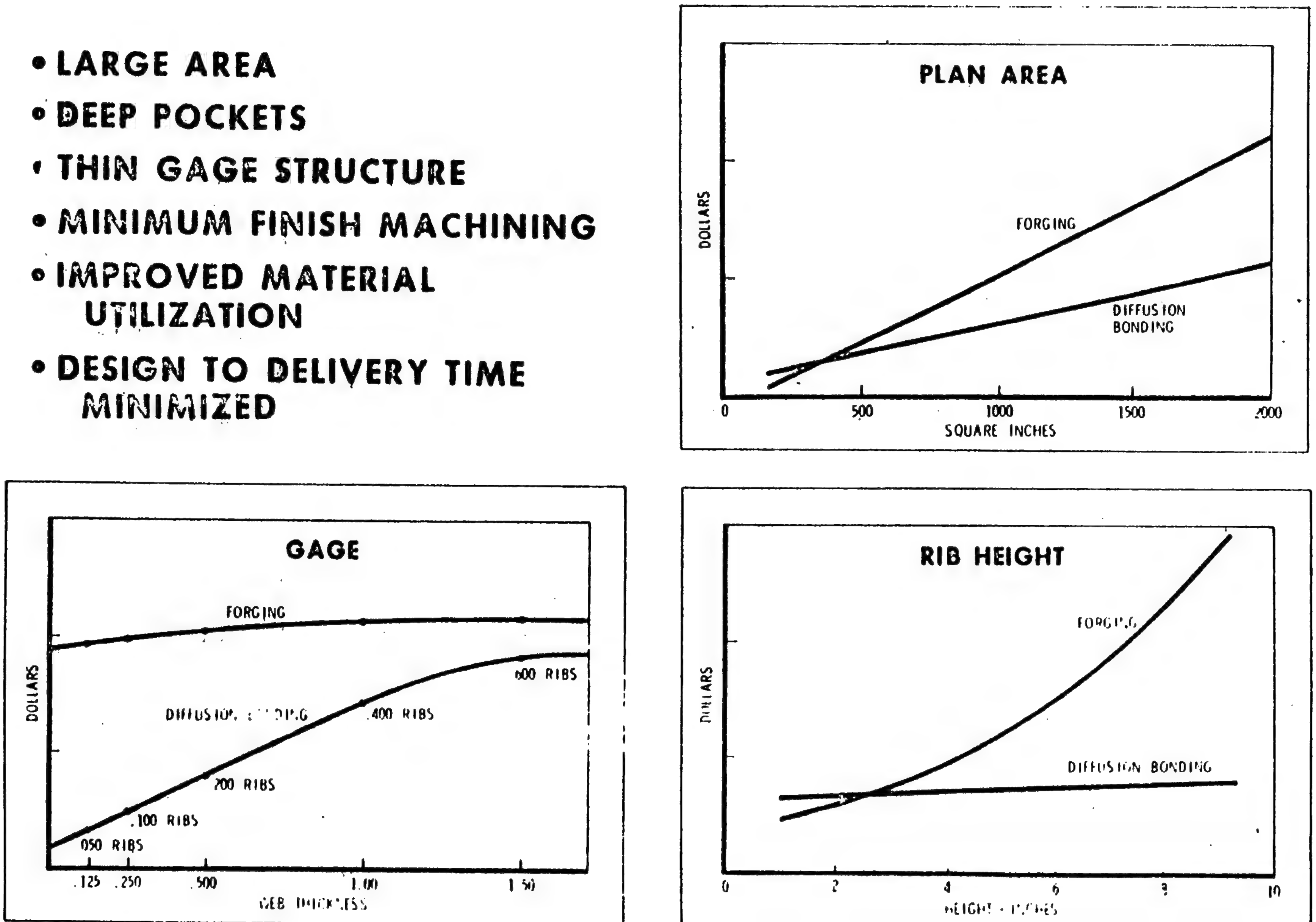


Figure B.27 - Costs for Typical Wing Covers

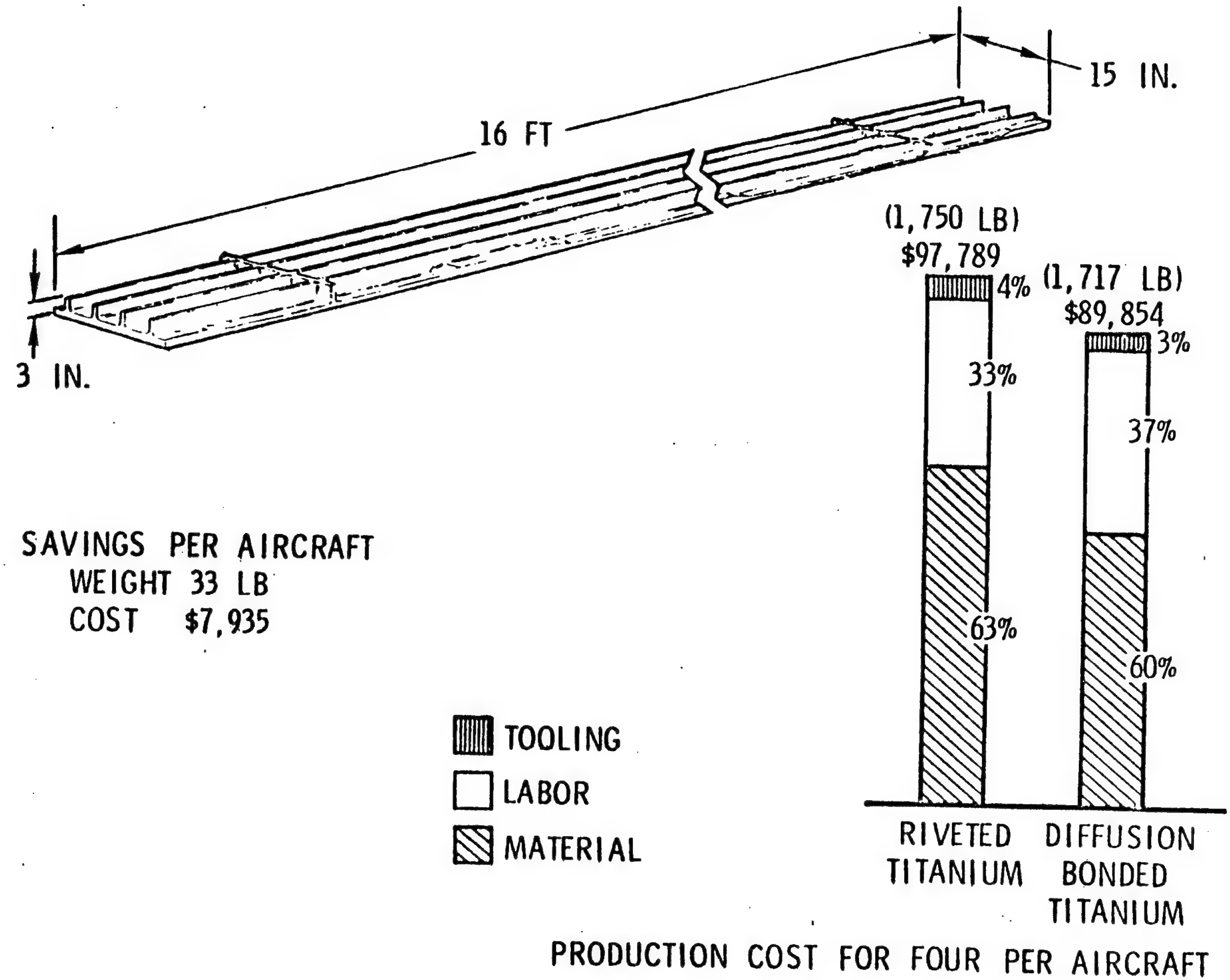


Figure B.28 - Costs for Titanium Main Center Box Spars

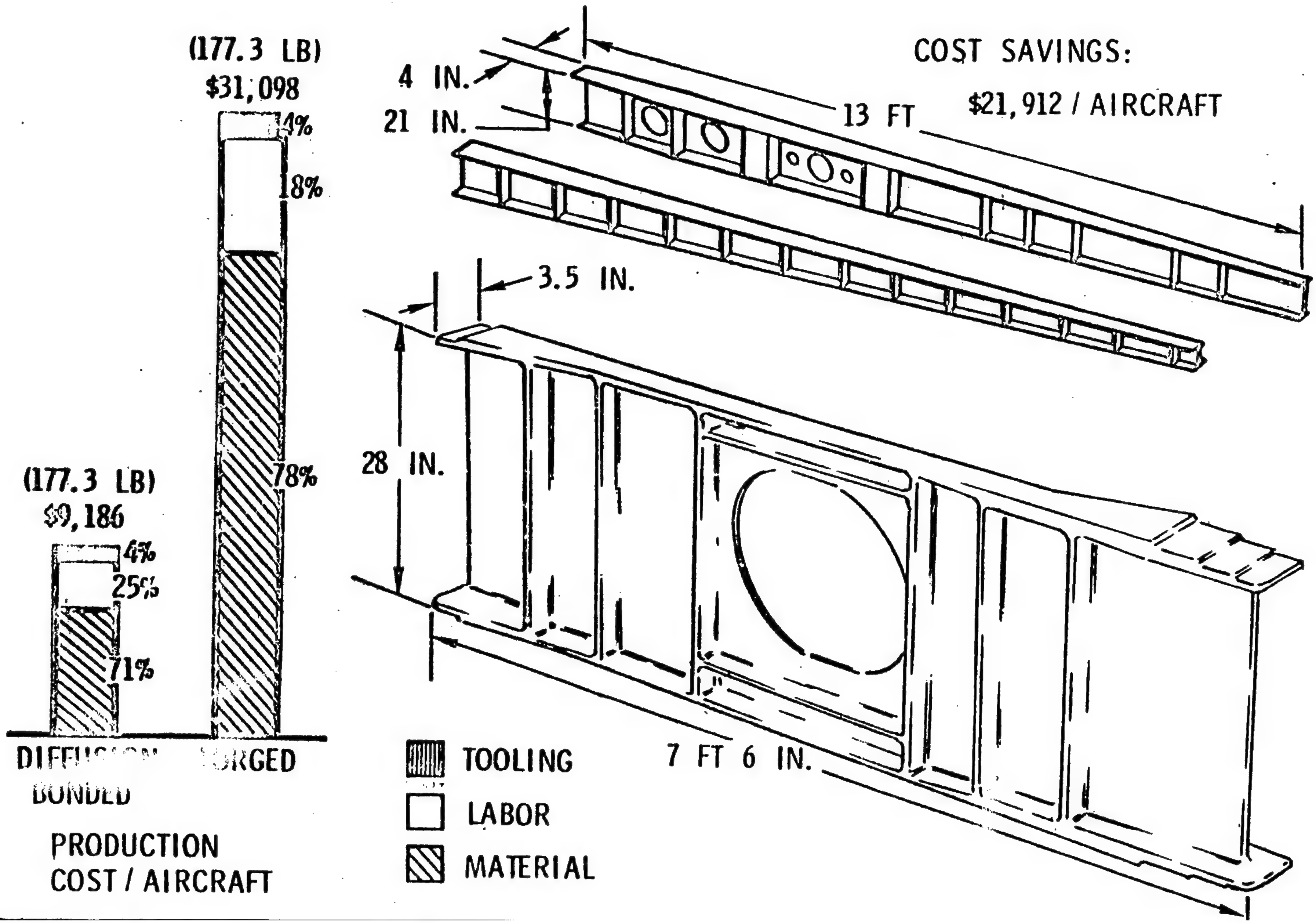
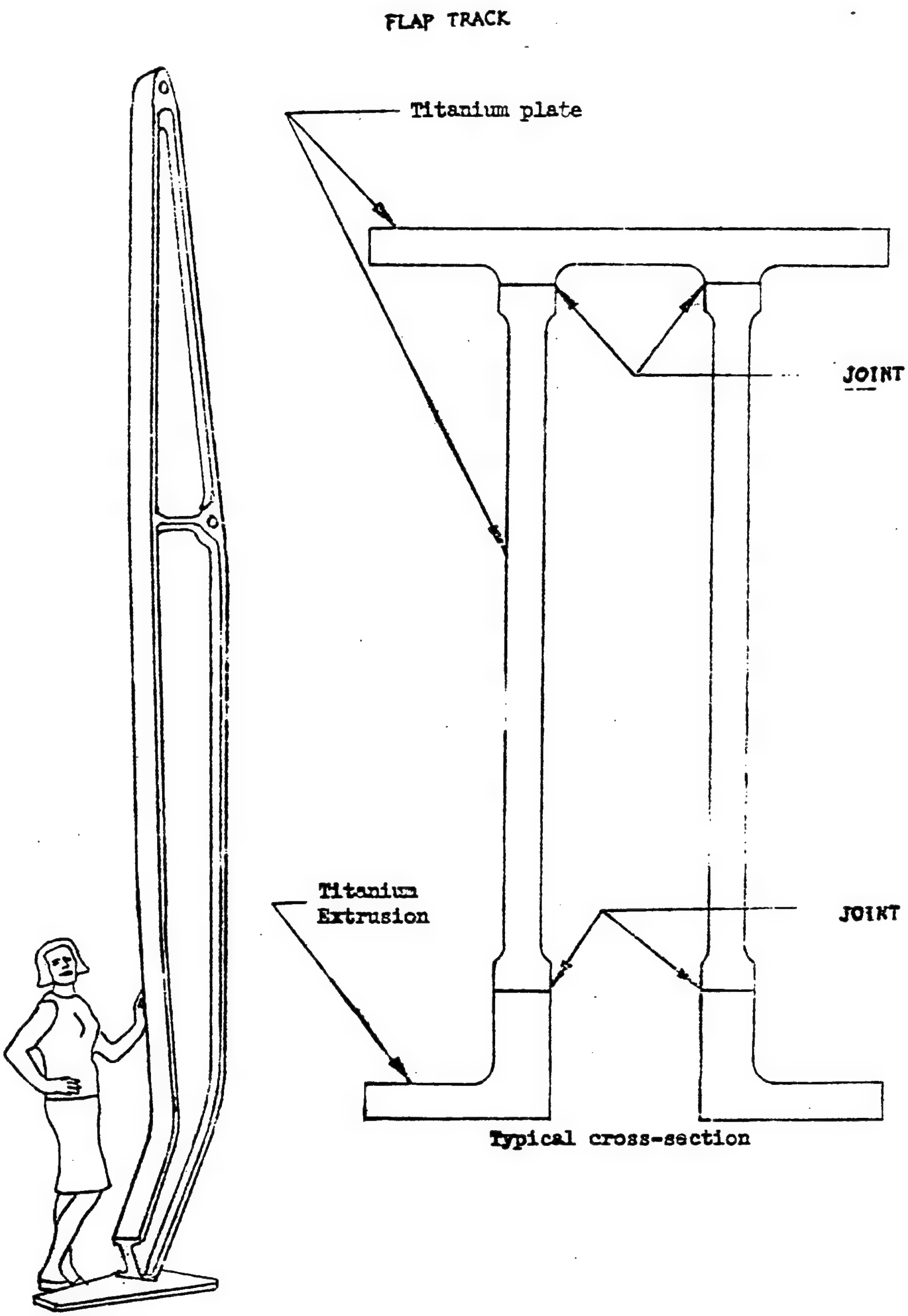


Figure B-29 - Titanium Flap Track Component



E. Electron Beam Welding

Electron beam welding is a fusion welding process which has particular attributes in the joining of titanium. The vacuum environment in which the process is performed precludes contamination by such gases as hydrogen, nitrogen and oxygen which can cause embrittlement of titanium weldments. The high depth-to-width ratio of the fusion zone and the narrow heat affected zone of electron beam weldments make possible significant reductions in the number of weld passes required compared to the GTA process. In addition, distortion due to weld shrinkage is virtually eliminated.

The process provides a joint which after machining and stress relieving, has 100% joint efficiency in static tension and fatigue. Local padding to provide additional factors of safety (reducing the stress in the weld) are accomplished with minimal weight impact due to the narrow weld zone.

The precise location and narrowness of the weld zone greatly facilitates inspection which has and will continue to hamper the broadening of applications of large surface area joining techniques such as brazing and diffusion bonding.

In spite of this fact, non-destructive inspection and correlation of the results of such inspection continues to represent a significant cost fraction in the EB welding process. Continued pursuit of improved correlation techniques and automation of the NDI process is required.

The relatively high cost of electron beam welding equipment compared to GTA equipment is offset by lower recurring costs of joint preparation, set up, welding, cleaning, and filler metal usage.

It is recommeded that the electron beam welding process be considered as a joining technique for small assemblies through large structures.

IV. COMPILATION OF VALUE ENGINEERING

This analysis of value engineering clearly depicts the cost reductions possible by continued surveillance and emphasis. It supports the theme of this Air Force/Industry Cost Reduction Study. During the period from 1964 to 1972 a major aerospace manufacturer compiled cost reduction data related to aircraft programs. The following list contains items which have been found to be a source for cost reduction. The relative amount of cost reduction for these various items are graphically presented in Figure B.30.

A. Design Items

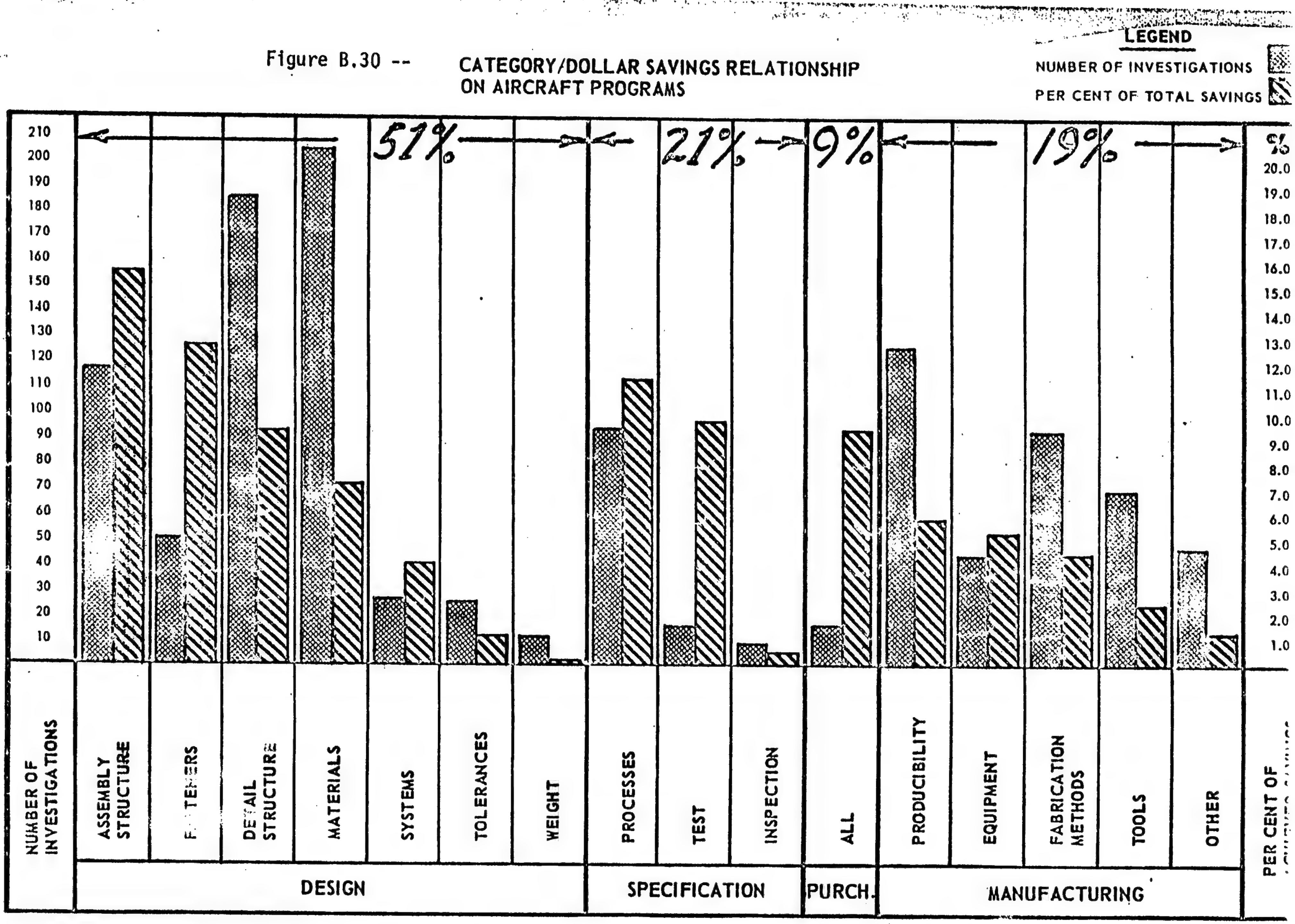
1. Assembly Structures - Where an assembly can be redesigned to reduce number of parts, method of assembly, etc. that will produce a cost reduction.

2. Fasteners - Where a change in fasteners reduced the cost either by part cost or install cost or sequence of build reasons or tooling required.

3. Detail Structure - Where the part is changed considerably to reduce the over all cost such as hog-out to forging or casting.

4. Materials - Where a change in the type, heat treat, specified thickness or a change to an extrusion configuration reduces the cost.

Figure B.30 -- CATEGORY/DOLLAR SAVINGS RELATIONSHIP ON AIRCRAFT PROGRAMS



DATA BASED ON 1134 INVESTIGATIONS DURING THE PERIOD 1964 TO MID 1972

5. Systems - Where a method, part, etc. is used throughout the design but actually may be changed or replaced in certain areas to reduce cost.

6. Tolerance - Where a tool call-out can be changed without affecting the part function.

7. Where weight reduction was primary reason for the change.

B. Specification

1. Processes - Changes in paint, chem-mill, bonding, coatings, shot peen, etc. that reduce cost of work or materials used.

2. Test - Changes that reduce or eliminate mandatory test operations.

3. Changes that reduce or eliminate mandatory inspection requirements.

C. Purchase

1. All - Where a change to the part or assembly enables buying at a reduced price such as a standard part for a special part.

D. Manufacturing

1. Producibility - Changes made to parts or assemblies that are specifically to reduce the fabrication or assembly cost.

2. Equipment - Procurement of equipment specifically to reduce the cost of certain parts or assemblies.

3. Fabrication Methods - In-house changes relative to how a part or assembly is produced.

4. Tools - Tools made specifically to reduce the cost of certain parts or assemblies.

5. Other - In-house items of cost reduction relative to administration, operation, etc.

In summary, for the 1100 pluse valve analyses conducted, the cost savings distribution was:

51% from design changes

21% from specification changes

9% from changes to purchasing practices

19% from changes to manufacturing methods and/or procedures.

These analyses also support the"schedule compression" conclusions made in Section I.A - discussions related to Figures B.10 and B.11.

V. QUALITY ASSURANCE

A. Cost of Quality

In order to determine the cost of the quality function as related to the aerospace industry, the Aerospace Industries Association of America, Inc. conducted a Quality Resources Study in 1970. The data contained in that report was used to present the average percentages and/or ratios of costs incurred in prevention, detection, and losses related to the quality of airframe and engine components. To better understand the functions that go into the total quality costs, a breakdown of the elements which make up these three categories is presented below:

1. Prevention Costs

Design Review - Reviewing engineering specifications, analyzing product quality requirements, developing statistical techniques, establishing workmanship standards, reviewing tolerances and requirements for maintainability.

Data Systems & Reporting - Systems engineering, manual or mechanized data reporting and associated data processing utilized by quality assurance.

Quality Assurance Manual - Initiating and updating procedures and instructions that describe quality policies, quality engineering techniques and quality systems.

Quality Audits - Evaluating actual conformance to establish quality policies, standards, procedures and instructions.

Reliability/Parts Engineering - Specialized exercise and promotion of reliability disciplines to enhance and improve product integrity and performance.

Quality Program Planning - Comparing specified or implied customer requirements with capabilities and converting into specific program plans, preparing bid proposals, etc.

Quality Training - Developing, maintaining and implementing classroom and laboratory quality training programs whose objectives are to upgrade Quality Assurance capabilities and/or lead to formal certification in a process, technique or discipline. Additionally, "Zero Defects" type programs.

Supplier Analysis - Evaluating vendor capabilities from past performance reviews, surveys of facilities and procedures. Verifying adequacy of requirements transmitted to vendors, i.e. purchase order review, etc.

Other Prevention Expense - Secretaries, telephone, telegraph, travel costs, etc. not specifically included elsewhere, but which are considered part of defect prevention or outside - procured materials and equipment.

2. Detection Costs

Inspection and Testing - All salaries and wages paid to inspection personnel inspecting incoming material, work in process, finished product and shipping inspection. Excluding cost of capitalized inspection/test equipment. Expensed gages and consumable supplies. Excluding re-inspection retest and trouble-shooting which is covered in loss category.

Source Inspection - All costs associated with physical tests, inspection or surveillance at the supplier's facilities by contractor personnel.

Laboratory Testing - Costs associated with evaluating the quality of raw material and special processes as done by the Materials or Chemical Lab (e.g. plating tests, metallurgical analysis, etc.)

Inspection Technology - Designing and developing new inspection techniques and equipment.

Inspection/Test Planning - Determining the characteristics to be checked, the equipment to be used, the procedures to be followed, the records to be kept and the type, degreee and location of inspection and testing.

Calibration and Maintenance of Inspection/Testing Equipment - Salaries and wages of personnel engaged in comparing, maintaining and adjusting equipment to standards.

Data Package Preparation - Paperwork preparation of unit for final buyoff such as preparing logbooks, etc. The collecting, sorting and filing of all quality records in this element.

Delegated Inspection Representatives - Contractor personnel acting in delegation capacity for the government (e.g. DMIR activity for FAA).

Other Detection Expense - Secretaries, telephone, telegraph, travel costs, etc. not specifically included elsewhere but which are considered part of defect detection or outside procurred materials and equipment.

3. Quality Losses

Scrap - Net cost of labor and material which does not meet quality requirements and cannot be corrected or used as is. Excluding design changes and surplus inventory.

Rework and Repair - Costs of re-inspecting, retesting and correcting articles to restore them to specifications or allowable deviations. Excluding rework/repair due to design changes.

Material Review - Administrative costs of making disposition to use as is, scrap, rework or repair (MR/MRB activity).

Corrective Action - Salaries and wages of personnel engaged in trouble-shooting, determining cause of defects and proposing corrective action. Including customer complaints and failure analysis.

Corrective Action Follow-Up - Salaries and costs of monitoring or verifying effectiveness of corrective actions.

Warranty - The total costs associated with replacement of failures occuring within the warranty period.

Other Loss Expense - Secretaries, telephone, telegraph, travel costs, etc. not specifically included elsewhere, but which are considered part of quality losses.

The specific quality areas considered during this study and associated cost data are shown in Table B.XIX.

B. Discipline Interfacing

There is a need to establish requirements that necessitate the interfacing between design, strength, materials, manufacturing, and quality personnel. Contracts and/or specifications must require an analysis of each part to define the major structural components, the critical area within each part, the critical flaw size, and the critical orientation of flaws. This approach can result in reduced inspection cost but improved quality of inspection.

Table B.XIX - Quality Cost Factors for Airframe and Engine Components

Category		Airframe	Engine
Total Quality Costs as a % of Sales		4.5	4.2
Q.A. Dept. Operating Costs as a % of Sales		3.4	3.8
Prevention Costs	as a % of total Quality Cost	15.4	20.3
Detection Costs		57.3	64.8
Losses		27.4	15.0
Q.A. Manpower	as a Ratio to Mfg. Direct Labor	16.3	35.8
Direct Inspection		10.2	32.5
Subassembly	ratio of Direct Inspection to Mfg. Direct Labor	12.4	25.2
Final Assembly		9.3	350.0
Supplier Control		0.6	0.7
Receiving Inspection	Quality Costs as a % of Purchased Matl. Costs	0.7	1.2
Receiving Functional Test		0.4	0.1
Receiving Laboratory		0.3	0.3
Total Purchased Material Control		2.8	2.4

Effective use of NDT demands selection of the appropriate technique and the definition of inspection criteria that is based on engineering requirements. This can be provided by close coordination between design, structures, and NDT personnel. Limitations and advantages of each NDT technique and the product from variables that affect the test results must be considered. Techniques for ensuring adequate inspection coverage must then be discussed.

In the past, material and forging suppliers inspected parts to find the discontinuities most likely to be present; little or no attention was given to engineering needs, i.e., flaw size or orientation. With the above information, the vendors have knowledge relative to the orientation of flaws that can be most detrimental in relation to the applied stress direction in addition to their knowledge of the probable orientation and location of processing defects.

C. Acceptance Criteria

The establishment of acceptance/rejection criteria must be accomplished to reduce the unnecessary scrap, costs, etc., that occur when material contains defects, metallurgical characteristics, mechanical properties, chemical analyses, etc., that are different than the specification requirements. This may require more material characterization, fracture mechanics, or mechanical testing programs.

As an example, an appropriate engineering approach is to base the NDT defect acceptance criteria for a particular component upon the particular loads that the component must withstand and the quantitative defect resolution capability of the NDT techniques chosen. Investigations

need to be conducted to establish the minimum detectable flaw size for NDT. In addition, NDT techniques must be applied to various structural test programs in order to develop further quantitative information.

The appropriate NDT acceptance criteria can then be established through discussion with strength and design personnel as to what sizes of discontinuities are structurally significant. In many cases, the component should be zoned for several acceptance classes to reflect the varying stress levels that are present in different areas of the component. The critical orientation of flaws with respect to the loading direction should be established to aid in inspection. The establishment of critical orientation is important since this orientation may differ from the probable orientation of processing defects.

The following example is given to illustrate the manner in which the establishment of acceptance criteria can be used to reduce inspection costs of titanium components:

Fracture mechanics analysis may be used to establish maximum flaw sizes which will not grow to failure during the design life of the product. Inspection requirements can then be selected to ensure that production hardware will not contain flaws which are larger than the critical initial sizes (see Figure B.31). In some cases, this approach will reduce the total area of a given part that requires ultrasonic inspection. For example, if the maximum allowable flaw size is greater than the section thickness, an existing flaw would be surface connected and could be detectable by liquid penetrant methods. The net result of this approach is more effective utilization of ultrasonic inspection.

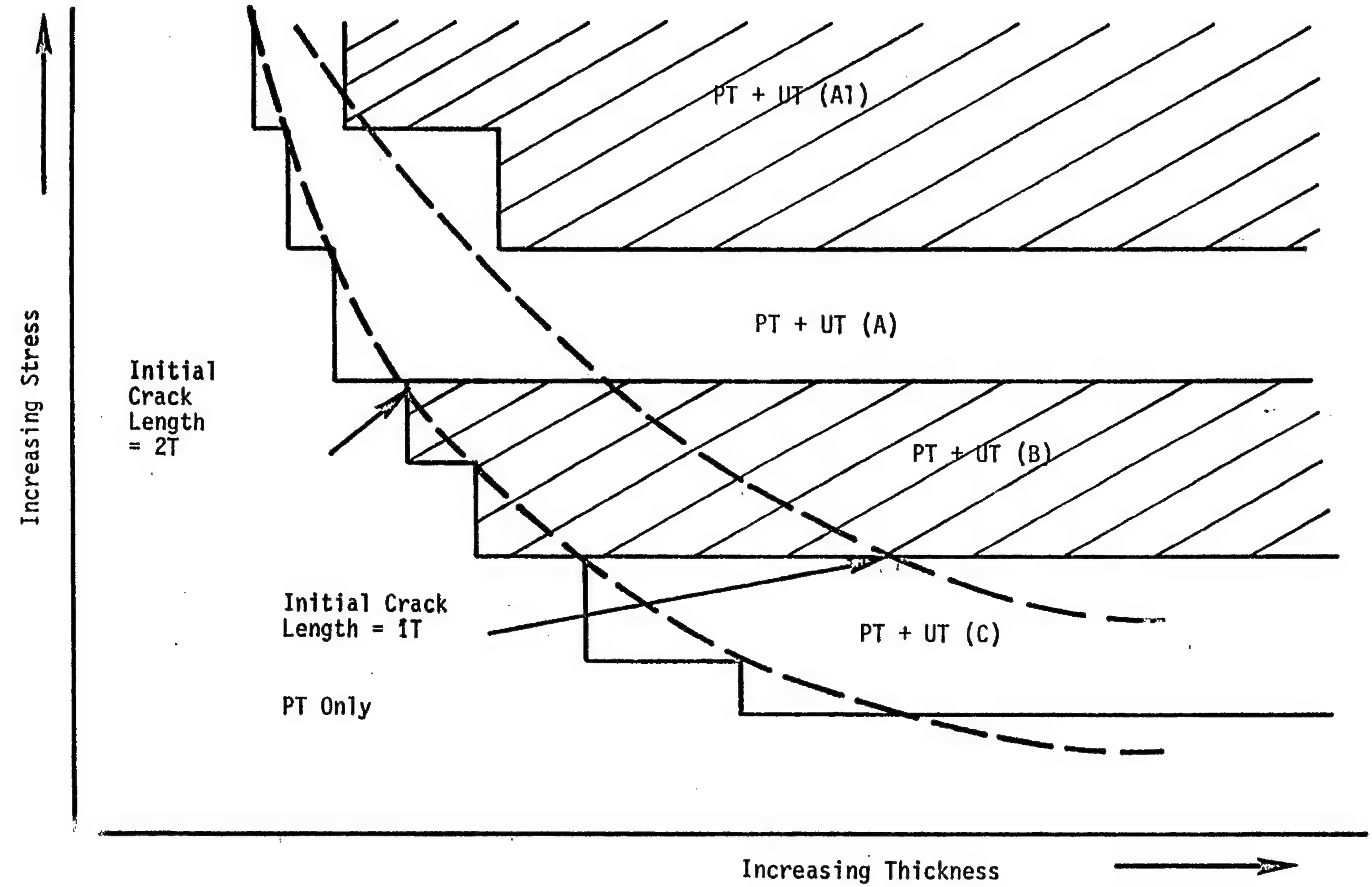


Figure B.31 - Typical Acceptance Criteria

With the ability to define acceptance criteria (flaw size) in a component such as a final machined part by fracture mechanics, the zoning concept for ultrasonic inspection can be implemented. By utilizing selective ultrasonic inspection along with complete penetrant inspection, it becomes economically feasible to inspect the final machined part in lieu of performing the undesirable intermediate die forging inspection provided a reliable and meaningful starting stock or preform inspection is performed.

VI. RECOMMENDATIONS

The following paragraphs consist of areas where cost reduction in primary airframe structures could be realized.

A. Parts Reduction

General - Proliferation of detail parts and the requirements to assemble these with fasteners is the heart of the cost problem. Reduction of parts by increase of size of fuselage structural components suggests a 20% weight improvement and an attendant 30% cost reduction potential in fabrication.

Current Status - Aircraft producers have examined this problem in the past. Some in fair detail, others only to realize that the potential exists. A program in adequate depth is needed to fabricate and test candidate fuselage structures that will look at frame stabilized sandwich or whatever appears most feasible.

Recommendation -

1. Reduce the number of detail parts and fasteners in a selected fuselage panel by fabricating a large bonded structural panel. Size should be clearly applicable to large transport/bomber fuselage.

2. Examine the possibility of complete elimination of the stiffener, shear clip design approach and wider spaced frames with increased skin thickness or categorizing of minimum skin gages and their resultant frame spacing to achieve desired strength levels.

3. Examine the possibility of designing an integrally stiffened fuselage by roll bonding, ultrasonic bonding or adhesive bonding to join skins and stringers.

4. Pursue any and all potential NDT methods to quantitatively examine bonded structure preparation and the resultant joined structure to ensure acceptability.

A wing and empennage multispar panel construction is suggested. It should consider aluminum brazed titanium structures to reduce corrosion problems and increase structural efficiency. This reduces number of parts and fasteners. Work is needed to produce data on panel cost, material input, etc.

B. Reduction of Metal Removal

General - The use in aircraft of higher performance materials such as titanium alloys has increased the cost of building aircraft structural components due to the higher cost of the raw material and the higher cost of machining. For equivalent parts it has been roughly estimated that costs of producing them in titanium is approximately five to seven times greater than in aluminum. To a large degree, this cost is a direct result of the limitations of the current state-of-the-art of metalworking technology to produce close to net dimension forgings and extrusions. Approximately 80% of the material purchased goes into chips. The reduction of the buy to fly ratio will significantly reduce the cost of producing these parts and permit the increased utilization of these materials in future aircraft.

Recommendation - A number of new techniques appear to have potential to make significant improvements in reducing end item manufacturing cost by reduction of metal removal.

Aluminum stepped extrusions are currently available for wing spars, but integrally stiffened rib wing planks with a heavy end have not been produced. Development of die designs and production techniques for stepped ribbed panels would result in a significant reduction in metal removal. Similar development of tapered shapes would also reduce metal removal.

Isothermal forging has shown capability of producing near net parts in small plan view area sizes. Further development is required to reduce the current high cost of dies and to extend the process to larger size parts.

Conventional forging processes can be improved to reduce scrap and increase material utilization by techniques for producing forging preforms. Powder metallurgy, friction welding, electron beam welding, casting, and diffusion bonding are potential methods that should be explored to produce preforms.

Diffusion bonding methods need further development to produce near net configurations in large complex components. Although significant progress has been made to date, there is a need to improve controls on deformation, atmosphere, and to improve the tooling materials for longer life.

C. Reduction in Metal Removal Costs During Early Production or Limited Production.

The selection of a forging for use in an aircraft structure usually results from structural requirements or from a desire to reduce metal removal. Neither of these objectives is changed. There are, however,

at least two circumstances under which aircraft prime structural members are machined from large billets or blocker forgings; (a) when production quantitites do not justify forging die costs, or (b) in the early phases of production when a design may be subject to change or when there is inadequate lead time between drawing release and part need date. Both cases are frequent occurrences particularly in major military programs.

Recommendation - Develop means for low cost, diffusion bonded, Electron Beam welded or brazed billets approximating the configuration of an optimized forging. Use of this technique would:

(a) Reduce metal removal in instances in which production runs do not justify forging dies. It is anticipated that forming of shapes by diffusion bonding or brazing would, in many instance, be less costly than excessive metal removal.

(b) Significantly reduce lead time between engineering drawing need date and first article need date. The effect could be either a reduction of "crash costs" or a longer design cycle within which to finalize design in accordance with the latest loads data. Normal lead times for major forging vary between 35 and 40 weeks. Laminated or "built-up" shapes could be produced in four to eight weeks.

(c) Within limits, grain direction could be oriented to design requirements.

(d) Accommodate changes without costly die changes.

D. Primary Structures Assembly (Material Supplier Viewpoint)

General - Larger components assembled with fewer and cheaper fasteners appear to offer the most opportunity for cost reduction. Large components however usually require more machining because they are not as

well defined as small components. Machining costs are controlled by the material type and the amount removed.

Recommendations -

1. Reduce fastener costs by standardization or elimination (ex. elimination of proprietary designs, limitation of sizes, etc.).

2. Provide larger components nearer to net form praticularly when the material is expensive and/or hard to machine (ex. net or near net forgings, diffusion bonding, EB welding, extrusion to size, neutral axis bonding, etc.).

3. Improve the performance characteristics of materials that are already available in near net forms and/or are easy to machine (ex. increase static properties without loss of fatigue, fracture throughness, SCC, etc).

4. Improve machining capabilities in all materials.

E. Possible Titanium Cost Reductions - Mill Product

Recommendations -

1. Electrolytic Sponge Production - Estimated cost reductions of 10% based upon decreased raw material and labor - bypass Kroll

2. Increased Volume of Mill Product Sales - Current domestic ingot capacity approx. 85×10^6 lbs. Est. 1972 ingot production 35×10^6 lbs.

3. Standardize on Industry Specification;Stock Sizes, Inspection Requirements. - Allows for less duplication, safer inventory, simpler production control.

4. Beta Alloys are Cheaper to Produce, Particularly for Flat Roll. May be cold reduced $>$ 90% without annealing; potentially cheaper to form. Needs work on STA and ST ductility and toughness.

F. Possible Titanium Cost Reductions - Fabricated Product or Alloy

Recommendations -

1. Titanium Powder Metallurgy - May enable forging closer to a net part, or produce a part from alloys that could not otherwise be forged.

2. Cost Drivable Titanium Beta Alloy Rivet - Alloy should be stable to 500°F and inexpensive to produce as wire.

3. Development of 1200°F Titanium Alloy with Suitable Coating - Main thrust is to increase volume in engine applications.

4. Welding and Machining Developments - Aimed at less expensive and more efficient procedures for onsite welding for shipyards and chemical plants, possibly laser drilling, and coated electrode welding.

G. Reduce Fastener Costs

General - Conservatively, 15% to 25% of aircraft prime structure cost is attributable to fasteners, their hole preparation and installation. Of this, between 30% and 50% is caused by precision hole preparation, the balance is the cost of the fastener and its installation. Overall fastener system costs are also increased by the enormous variety of sizes, grip lengths, material types and heat treat, and the excessive costs of non-standard fasteners. Further, there is some evidence which indicates that the high cost, precision fastener systems do not necessarily enhance fatigue life to the extent originally anticipated.

Current Status - There is some work currently in progress directed toward a reduction of fastener costs. There is limited work directed toward expanding and upsetting high strength-to-weight ratio metal rivets and other efforts directed at reducing mechanical fastener costs. For the most part, however, these efforts are not at a level in consonance

with the portion fasteners contribute to primary structure costs.

Recommendation - It would appear that there should be an extensive effort directed at reduction of fastener costs. The organization and content of such a program should result from recommendations of all those associated with fasteners (alloy producers, fastener manufacture aircraft structures designers and aircraft manufacturers) but as a minimum should address itself to:

(a) The development of an alloy or alloys suitable for ease of manufacturing.

(b) The acceleration of the development of methods to install low cost fasteners -- both high-energy-rate and low-energy-rate method.

(c) The development of more reliable methods of determining the fatigue characteristics of a fastener system.

(d) Evaluate all present and potential methods of producing fatigue resistant fastener holes including coining, interference fit, expandable fasteners, etc.

(e) Develop methods to reduce deburring and destacking.

(f) Determine the optimum parameters for drilling holes in combinations of dissimilar metals.

(g) Revise existing fastener standards to tighten fastener tolerance thereby permitting broader tolerances in the high cost hole.

(h) Standardize on fastener materials (Ti, Al, A286) and diameter for each type (lockbolt, hex, flush head) and one strength level.

(i) Standardize on one strength level (160,000) for shear bolts and one strength level (220,000) for tension bolts.

(j) Generally reduce quantities of fastener types, sizes, etc. The best of all would be a high strength-to-weight ratio slug rivet that could be installed using true mass production techniques -- an obvious conclusion but well worth careful consideration when it is possible to reduce the overall cost of an aircraft structure by as much as 20%.

H. Reduction of Assembly Costs

General - The increasing structural and aerodynamic complexities of modern prime structures are resulting in excessive amounts of labor expended on hand blending, pre-fit, shimming and trimming. In most instances the requirements for close fit are dictated by the necessity to reduce or eliminate enduced residual tensile stresses.

Recommendation - There are two possible solutions to a majority of these high cost activities:

(a) Development of a structurally adequate "liquid shim" and

(b) The development of a method or methods for local relief of stresses induced during assembly.

There has been limited work in both areas; enough to indicate a justification for significantly increased financial support.

"Liquid shim" is available in several compositions and some limited work on improving the structural characteristics. The principal deterrant to a major development is the lack of agreement between aircraft structures designers on the use of "liquid shim" and its specifications.

Local stress relief has even explored using shot peening.

In current production between 15% and 25% of all assembly labor is consumed in hand blending, pre-fit, shimming and lost time due to Material Review Board activities. A major portion of this labor would be eliminated with the successful development of solutions to production mis-match problems.

I. Reduce Titanium Skin Plank Fabrication Costs

General - Sculptured, heavy skin panels, particularly Titanium, are extremely expensive to machine and form to the complex contours required by modern high-performance aircraft. Each new generation of aircraft designs results in requirements for more sophisticated contours and sculpturing, and further advances in the art of load and stress analysis and aerodynamics will, in all probability, produce even more severe manufacturing requirements.

Recommendations - Develop the arts of diffusion bonding and brazing to the point that laminated panel sections can be simultaneously bonded or brazed and formed to contour in one single operation. Taper rolling processes for planks warrant consideration.

The art of brazing and/or diffusion bonding of Titanium has advanced to the point where it is now conceivable to develop methods of simultaneously hot forming and diffusion bonding a number of layers of relatively light gauge Titanium into a compound contoured skin plank with all sculpturing requirements eliminated.

Reductions of up to 50% in production labor could result with overall fabrication tooling costs being approximately equal.

J. Reduction of Detail Parts

General - Recent studies indicate that the large number of detail parts found in conventional airframe structure has been a major contributor to the high cost of airframes.

Current Status - Some work has been done in the evolution of new structures concepts for fuselage and wings that show promise for very significantly reducing the complexity of structure on future airplanes. The cost for the design, construction, testing and evolution of the optimum designs that reduce manufacturing cost to a minimum commensurate with engineering requirements is beyond the funding capability of private industry today.

Recommendations - Funds should be made available for the evolution of less complex and less costly designs that will meet the reliability requirement of the customers. New structure concepts must be extensively tested and flown by the customers to get widespread customer acceptance. It is imparative that these new structures be built and flown in an environment that will accumulate a large amount of experience in a short time.

In conjunction with this design evolution work, manufacturing and quality control methods should be developed that will insure reliable low cost production.

The evolution of new design concepts is required for major critical structural members that can improve reliability and reduce cost through the use of joining methods other than conventional fastening.

K. Computer Aided Design and Manufacturing (CAD/CAM).

General - The use of Numerical Control (NC) and Direct Numerical Control (DNC) is well established and has resulted in cost savings as well as the ability to handle larger and more complex shapes than before NC. A large part of the time and cost associated with NC and DNC is the translation of engineering data into machine instructions.

Considerable work has been done toward an interface between computer definition of parts in engineering and the NC of DNC instructions. Several companies are active in this area.

The heart of such a system is the mathematics used to define the shape and the storage data file for this information and all the related data generated by users. It is essential that the mathematical system for shape definition be suitable for engineering analytical purposes and drawing preparation as well as for NC code.

Status - Considerable work has been done in this area by most large airframe companies. "Computer Aided Design" is being used for design of airframe components, preparation of drawings, making three dimensional layouts of kinematic systems on automatic drafting machines and numerous other detail applications. NC is in prevalent use and DNC is being used in several areas. The interface between CAD and CAM is being worked by most companies. Several systems are in existance. However, none are complete and they are probably not compatible.

Cost Saving Areas

Significant Cost Savings can be made through the additional use of Computers in Manufacturing in the following areas:

1. AUTOMATE PLANNING 10% to 50% Saving
   (Planning labor 6% of Engineering labor)

   PROCESS SPECIFICATION
   Industry & Government

   CANNED STANDARD PLANNING

2. SIMULATE SHOP LOAD $2000,000 +/year

   DYNAMIC LOADING OF SHOP AND EQUIPMENT

3. AIDE TOOLING

   TOOL DESIGN
   Detail Tools
   Assembly Tools
   Cutter
   Etc.

   TOOL CONTROL & INVENTORY

4. PROGRAMS FOR SPECIAL MACHINES

   WING MODEL FLOW TIME REDUCED 45 SHIFTS TO 25 SHIFTS

   FLUTTER MODEL SPARS REDUCED 30 to 20 SHIFTS

5. MACHINABILITY DATA BASE

   MATERIAL SPECIFICATIONS RELATED TO OPTIMUM CUTTER CONFIGURATION

Automated planning can save up to 10-50% of the cost of preparing planning for a new airplane. One recent airplane program utilized 1600 people at the peak of the effort.

The requirement for industrial engineering help and tool designers can be very significantly reduced through the use of computers in simulating shop load and through the use of the computer and plotters to do much of the drafting associated with the design of tools.

The flow time for the making of wind tunnel models can be reduced by from 10% to 50% through the developing of special programming

methods for special machines.

Manufacturing cost can be reduced by developing a machinability data base that will adequately correlate, material specifications, processing methods, cutter related data cost, and the surface integrity and reliabilit of the process.

Recommendation - Since time compression in both engineering and manufac ing has been shown to be a cost contributor and since, realistically, programs will not be "stretched" to save this cost, it is necessary to improve the efficiency of response to program demands. Continued development of the CAD/CAM systems and interfaces provide a realistic approach to cost reduction and to product improvement.

It is recommended that programs be instituted to bring together current activities in this area and to concentrate on the mathematical system and the interface between engineering and manufacturing. Emphasis on the CAD/CAM is high because it is probably the greatest single posibility of achieving a major cost reduction in airframe production.

L. Reduction of Quality Control Costs

General - It has been conservatively estimated that between 4% and 5% of all aircraft costs are incurred either directly or indirectly by quality control. Many of these requirements are believed to be overlapping, excessive or unnecessary.

Recommendation - In light of the costs of modern aircraft, a reduction of quality control costs could be significant. Therefore it is proposed that production life-cycle quality control costs be studied in order to:

(a) Reduce inspection costs by mechanization of NDT and other inspection tasks.

(b) Development of intermediate inspection processes reducing the need for 100% and item inspection (primarily NDT).

(c) Characterization of material defects with regard to engineering requirements.

(d) Identify and eliminate overlapping or excessive quality control requirements.

M. Primary Structure Design Efforts

General - Program contracts often call for current state-of-the-art designs that do not provide funds for design trade studies for the evolution of the optimum design for low cost quantity production prior to design go-ahead. Development funds are generally not allowed for manufacturing and engineering to develop design and processing changes to reduce production cost.

Current Status - Current commercial airplane programs have experienced very large cost reduction as a result of this type of effort.

Recommendations - Government funded airplane contracts should provide funds for trade studies that promote the evolution of the most cost effective designs and provide funds during production specifically directed at reducing production costs through design and manufacturing methods improvement.

N. Reduce Cost of Fuel Tank Sealing

General - The wide variety of fuel tank sealing techniques is a cost problem unique to the subcontractor. However, since between 20% and 40% of all aircraft structure manufactured is subcontracted, this problem is worthy of consideration.

The subcontractors are currently manufacturing many different sealed structures in which either the sealing philosophy or sealant, or both, differ. The end result is an excessive expenditure of labor hours in training and quality control not to mention excessive inventories.

Recommendation - The solution would appear to be the development of standard sealing techniques for the typical aircraft joints and the acceptance of those techniques by the aircraft industry. It is proposed that structures be made of available sealing and coating systems toward the end that industry standards can be developed for a majority of structural sealing requirements.

O. Productivity Increase

Current Status - American industry must improve its productivity. Much of the industrial equipment used in our country today is obsolete.

The rate of change of output per man-hour in manufacturing for the large industrial nations shows that Japan leads with a 14.2% increase in productivity and the United States is at the bottom of the list with the smalles increase of 2.1%. Since 1960 the output per hour of ten major foreign competitors has increased by the weighted average of 87%, while our output has increased by 34%. To improve this situation the U.S. must increase the rate of capital investment in modern productive equipment. The U.S. is installing new machine tools at a lower rate than others as noted below:

1971 INVESTMENT

Soviet Union	$1,260,000,000
West Germany	$1,110,000,000
Japan	$ 942,000,000
United States	$ 812,000,000

Much of the U.S. capacity is technologically adequate but is not as efficient as it should be and, therefore, economically obsolete. It has been shown by a McGraw-Hill survey that in 1968 14% of the manufacturing facilities operated by the large U.S. companies were obsolete and that the end of 1972 the number has grown to 16%. In addition to this condition, the industry faces conversion to the metric system.

Recommendation - It is extremely important that the U.S. promote equipment modernization to increase productivity by providing increased tax relief. Equipment conversion cost for change to metric should also be allowed as expense.

There are a large number of standards in the U.S. that must be converted from inch to metric, such as gear, thread, gages, etc. The government agencies should take action immediately to fund for this conversion. The first to be impacted by the conversion will be the aerospace industry because of the relatively high technology. They also will be seriously hurt by the lack of a rapid conversion because of the very broad subcontractor and small business supplier base. There must be a good tax incentive to promote this conversion.

P. Conduct Problem Oriented Seminars

General - One fallout from the panel discussions was the need for problem oriented technical meetings. The majority of sponsored meetings today are technology oriented and are comprised of enormous audiences listening to prepared presentations with little or no opportunity for private, small-group, technical exchange.

Current Status - There are many companies with small, problem oriented manufacturing technology development programs that are not reported in the literature or discussed in the large symposia. It is clear from the experience of these meetings that managers of these efforts are willing to participate in a give-and-take discussion of their work with people involved in similar efforts but are reluctant (correctly) to give away the "family jewels" to a 500 man audience.

Much money (conservatively, in the millions) is spent each year by the aircraft industry in the development of manufacturing technology, much of which is redundant. Since all of these costs eventually end up in delivered end items, it is clearly in the best interest of both the industry and the Air Force to insure that investments in this type of development are as efficient and productive as possible.

Recommendation - The Air Force should use its close association with the aircraft community to maintain a close liaison with all industry-sponsored in-house manufacturing technology development and act as a catalyst in the <u>transfer</u> of technology.

More specifically, it is proposed that the Air Force establish a focal point through which technical managers can learn of current development or to which specific manufacturing technology problems can be addressed. Further, when it appears profitable, it is proposed that the Air Force sponsor, and arrange for, saml1 technical working groups comprised <u>solely</u> of individuals who can contribute through directly related efforts, with the end result being a significant reduction in development funds that are wasted on redundant efforts along with bringing together the industry's most competent and interested technical talent for the solution to manufacturing technology problems.

PART C

SECONDARY AIRCRAFT STRUCTURES
PANEL REPORT

I. INTRODUCTION

This report is concerned with manufacturing Secondary Structures in airframes and its relative cost to the total structure. The report is divided into four main sections as follows:

SECTION II - General Cost Relationships

A. Relative Cost For Aircraft
B. Recurring Structure Dollars
C. Secondary Structure Cost

SECTION III - Summary Identification Charts

A. Doors
B. Fixed Edges
C. Control Surfaces
D. Air Ducts & Tail Cones
E. Miscellaneous
F. Installations
G. Cost Analysis - Number of Parts
H. Cost Analysis - Number of Rivets

SECTION IV - Recommendation Charts

A. Mechanical Fastening Systems
B. Hydraulics Installation
C. Actuators & Valves
D. Electrical Wires
E. Bonding
F. Castings
G. Titanium Tubing
H. Titanium Sheet Metal Fabrication
I. Titanium Sandwich Structures
J. Weldbonding

SECTION V - Supporting Operation Sheets for Current Fabrication

It was necessary first to define the relative cost areas in airframe manufacture developing specific costs in detail. Section II is included to delineate these relative costs for the broad categories: (a) primary structures, (b) secondary structures, and (c) installations. The results of this showed that the three were of almost equal importance for the airplanes selected.

In Section III matrix charts are developed which define the major parameters affecting costs for six principal categories of secondary structures. Actual costs representing five types of airplanes were assemble from historical data for forty-three secondary structure components. Because the six independent parameters, shown in the first six columns of each chart, did not give a clear representation of our objective, four additional parameters were developed which gave a better comparison for high cost. These are shown in the last four columns of each matrix chart.

These six matrix charts clearly showed relative high cost components, particularly in comparing the MH/LB column. However, it was necessary to go even further, because these matrix charts did not portray the reason for high cost nor the contributing factors for it. For this reason, operation charts for each of the forty-three components were developed which detail each fabrication operation, with numbers of parts and manhours associated with each. These are shown in Section V. In this way, it was possible to define specific causes for high cost.

II. GENERAL COST RELATIONSHIPS

For the purpose of analyzing cost associated with aircraft structures, the structures were categorized into primary and secondary structures. It was the purpose of this analysis to examine the secondary structures which were separated into six basic subdivisions:

- Control Surfaces
  - Spoilers
  - Flaps
  - Rudders
  - Ailerons
  - Elevators
- Fixed Edges
  - Wing, leading and trailing
  - Empennage
- Air Ducts and Tail Cones
  - Ducts
  - Tail Cones
  - Nose Cowl
- Doors
  - Access
  - Nacelles
  - Pressure
  - Cowl
  - Actuated
  - Unactuated
- Miscellaneous
  - Speedbrake
  - Canopy
  - Fairing
  - Wing Tips
- Installations
  - Electrical
  - Hydraulic

A. Relative Cost for Aircraft

In order to eliminate false conceptions regarding relative costs between secondary and primary structures, several charts were developed

such as the two pie charts shown in Figure C.1. This figure shows total aircraft structure costs as a percentage of the total aircraft cost. It can be seen that it represents approximately fifty percent of the total aircraft cost. The other 50% is in engines, avionics, and other such purchased parts. The pie chart on the right gives a cost breakdown of the airframe costs for a supersonic bomber, which is based on actual data. This chart shows that secondary structures and installations represent 62% of the total airframe cost. Secondary structures alone are of equal magnitude to primary structures. Therefore, secondary structures are indeed of primary importance.

B. Recurring Structure Dollars

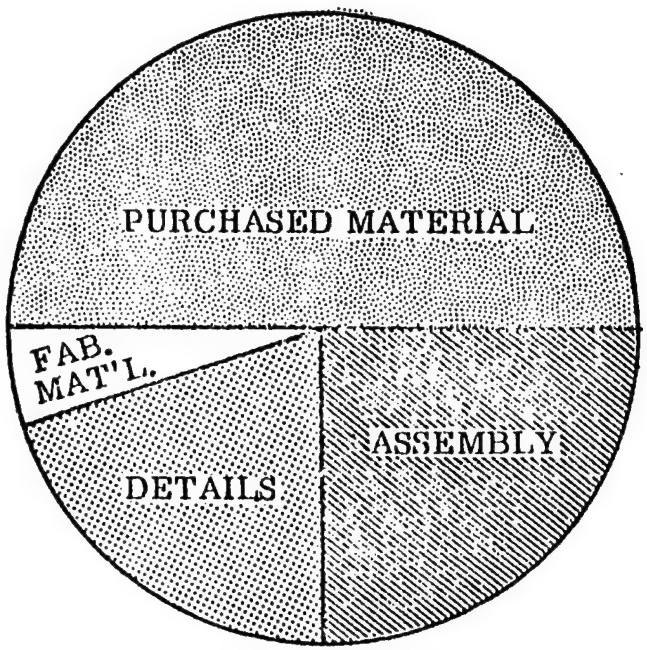
The next topic considered by the panel was recurring structure dollars in a typical transport aircraft as shown in Table C.I. Both primary and secondary structures are examined in this table, which shows the costs associated with various sections of the aircraft. It can be seen that the costs are not directly related between primary and secondary structures. It also points out that even on a transport without the installation costs that would be involved with all of the avionics, that secondary structures still represent 34% of the total recurring structure dollars. The table shows on a percentage basis, where the secondary structure costs are incurred.

C. Secondary Structure Cost

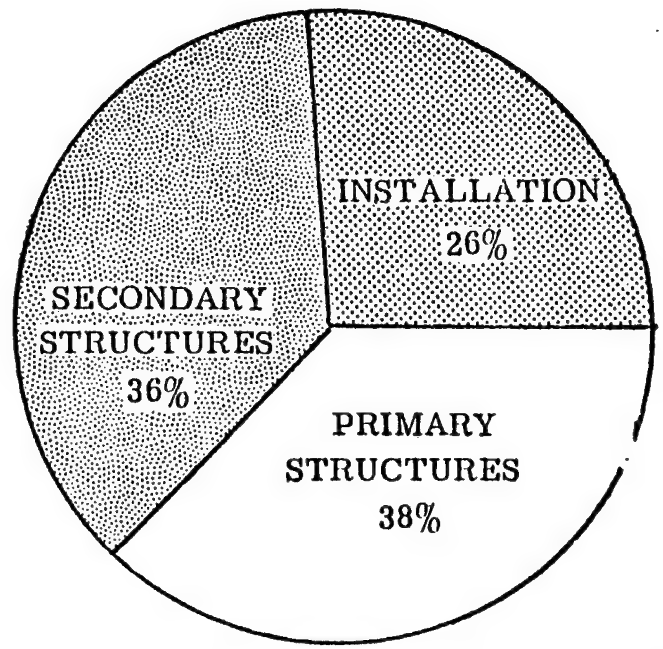
The delineation of secondary structures, as a percentage of the total airframe cost, are categorized in Table C.II for major components in both the supersonic fighter and supersonic bomber. Observations from this table are: First, the major cost item is in installations. Second,

Figure C.1

RELATIVE COSTS FOR A/C



TOTAL A/P COSTS



AIRFRAME COSTS
BOMBER-SUPERSONIC

TABLE C.I

RECURRING STRUCTURE
DOLLARS (1000)
TRANSPORT

	PRIMARY	SECONDARY	SECOND. %
HORIZONTAL TAIL	210	60	74%
VERTICAL TAIL	123	41	
FIXED WING	772	481	
CONTROL SURFACES		820	
BODY	2652	503	26%
TOTAL	3766	1905	
%	66	34	

TABLE C.II

SECONDARY STRUCTURES % OF TOTAL A/F COSTS

STRUCTURE	SUPERSONIC FIGHTER	SUPERSONIC BOMBER
WING AND TAIL	11.68	5.14
RAMPS		1.64
CANOPY	2.13	
RADOME		.87
DOORS AND ACCESS	5.00	8.00
PURCHASED PARTS	1.00	
NACELLES		15.08
INSTALLATIONS	16.28	26.50
TOTALS	36.09	61.28

the next most important areas are the nacelles, wing and tail type structures, and doors and other access structures.

The following section will analyze these structures to determine where the high cost areas are for each type of component.

III. SUMMARY IDENTIFICATION CHARTS

Matrix sheets were prepared for each of the six major Secondary Structure Categories. These sheets were prepared to look at overall cost considerations in an attempt to see where costs were and what relationships might best indicate problem areas. With this in mind the following areas were examined:

Weight
Material Cost
Total Cost (Material & Production Man-hours)
Manhours
Parts
Fasteners
$/lb
Man-hours/lb
Parts/lb
Fasteners/lb

Initial analysis of the matrix sheets resulted in the following considerations: (a) Material costs are generally only in the 10% range of the total part cost. However, when titanium is used the percent will be higher, but still quite small compared to production costs. Castings and forgings will also increase the basic costs, but will decrease production costs. This can be quite significant when the higher cost of castings and forgings are much less than decreased production costs. Less expensive castings and forgings, plus anything that can be done to further reduce production costs (such as closer net castings and forgings) are obvious considerations from

this analysis. (b) Since production costs are generally 90% of the total costs, this was the area chosen for detailed analysis by the panel. (c) Man-hours, parts and number of fasteners were examined as methods of defining the fabrication costs. Due to the different types of construction and size of parts, the quantities were then examined in relation to weight to get some uniformity for analysis. Dollars per pound was also examined. Since dollars per pound also takes into account the material considerations, the panel decided to take man-hours per pound as the best indication of fabrication efficiency (parts and fasteners both resulted in increased assembly costs and thus higher man-hours per pound).

The following sections contain a discussion of each component category selected for consideration. The matrix sheet for each section, and in some cases a schematic of a typical component of that category, follows the discussion.

A. Doors*

Data are presented in Table C.III on nine different door type structures which represented both different types of door structures (access, nacelles, cowl panels, etc.) and different types of aircraft (subsonic fighter attack, transport, supersonic fighter attack, etc.). Man-hours per pound varied from 1.4 (door 4) to 15.0 (door 7) for these structures. Door 4, using honeycomb to reduce both parts cost and assembly cost, was a large but simple-design door. Door 7 also used honeycomb, however, it was a

*Detailed Operation Sheets for these components and succeeding components are contained in Section V.

TABLE C.III - DOORS

	WEIGHT	MATERIAL $	TOTAL $	MAN-HOURS	PARTS	FAST-ENERS	$/LB	MH/LB	PARTS /LB	FAST/L.B.
Access Door (Nr. 1) F/A Subsonic (A-7) S/M - B/U	4.1	31.5	433	18	24	75	105	4.4	5.9	18
Access Door (Nr. 2) F/A - Supersonic S/M - B/U (F-14)	3.8	20	590	38	2	500	153	10	.5	132
Nacelles (Nr. 3) Transport S/M + H/C (DC-8)	1860	39732	144980	6861	2562	14880	78	3.7	1.4	8
Pressure Door (Nr. 4) Transport Bonded H/C (C-141)	341	1380	13980	480	123	-	41	1.4	.4	
M.L.G. Door (Nr. 5) Transport Bonded H/C (C-141)	420	3620	17640	1092	-		42	2.6		
Unactuated Door (Nr. 6) F/A - Supersonic (F-14) Bonded H/C	168	2856	9452	430	352	1800	56	2.6	2.1	11
L/G Door (Nr. 7) F/A - Supersonic Bonded H/C (F-14)	32	760	7960	480	64	-	250	15.0	2.0	-
Actuated Door (Nr. 8) F/A - Supersonic Bonded H/C (DC-8)	109	4597	12880	540	78	645	118	5.0	.7	6
Cowl Panel (Nr. 9) Transport Bonded H/C [illegible]	265	2990	19572	1081	488	4130	74	4.1	1.8	16

Figure C.2 - Door Nr. 1

EQUIPMENT ACCESS DOOR
FIGHTER / ATTACK - SUBSONIC

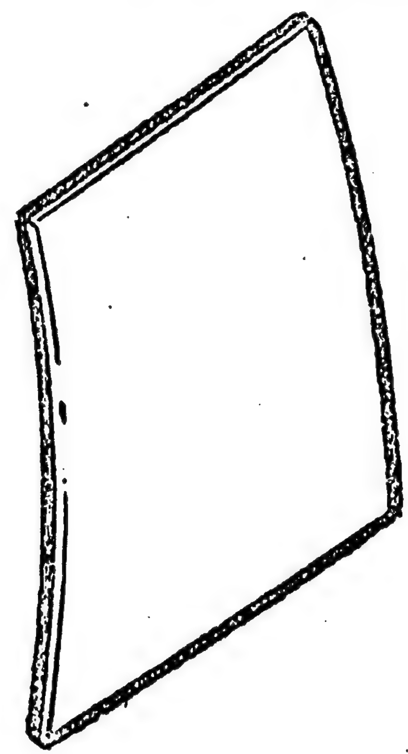
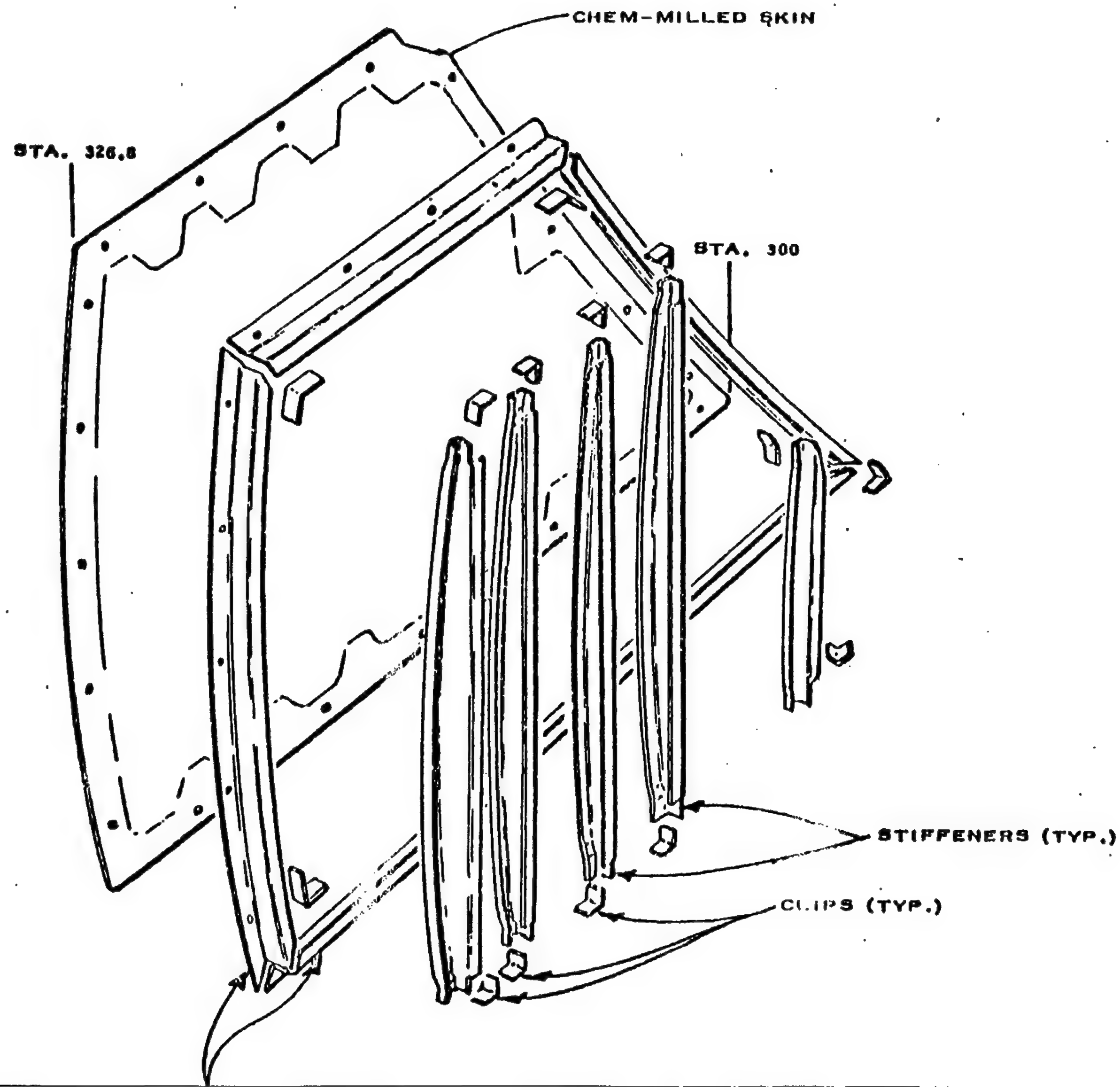


Figure C.3 - Door Nr. 1

EQUIPMENT ACCESS DOOR - EXPLODED SECTION



very small and complex (double contour) door located on a weight critical aircraft, therefore, every effort was made to reduce weight by chem-milling, machining, etc. These operations along with the double contour, increased costs drastically. In general honeycomb structures decreased assembly costs considerably, but often required increased fabrication costs which indicate an area for cost reduction. It was concluded that significant cost reduction was possible on door structures by: (a) reduction in parts and/or assembly cost for sheet metal build-up, (b) by reduction in machining cost, and (c) further reduction in assembly cost for honeycomb construction door structures.

B. Fixed Edges

Fixed edges were also examined with data obtained on nine structures as shown in Table C.IV. These structures included both wing and empennage fixed edges. Again a variety of aircraft are represented. Man-hours per pound ranged from 1.2 (Edge 2) to 7.0 (Edge 8). Edge 2 is inexpensive because it is a large, simple structure that uses standard size ribs and a large amount of automated rivet assembly. Edge 8 has boundary layer control which increases the cost of the edge considerably. The typical edge runs from 3.0 to 6.0 man-hours per pound, which is high. In general these high costs are attributable to both fabrication of parts, and assembly for sheet metal built-up structures. Those edges that have bonding assembly or honeycomb have a high percentage of their cost involved in the bonding of substructures as well as in final assembly. Again, as in the door structures, a large number of parts are involved with these type structures. Potential cost reduction areas are in either reduced machined parts and assembly costs as well as reduced bonding associated costs.

Table C.IV - FIXED EDGES

	WEIGHT	MATERIAL $	TOTAL $	MAN-HOURS	PARTS	FAST.	$/LB	MH/LB	PARTS /LB	FAST. /LB
Wing L/E (Nr. 1) Transport S/M - B/U	1056	8640	61200	4450	850		58	4.2	.8	
Wing L/E (Nr. 2) Small Cargo S/M - B/U	1800	5220	20922	2220	951		22	1.2	1.9	
Wing T/E (Nr. 3) Small Cargo S/M - B/U (707/KC-135)	531	873	17523	1062	400		33	2.0	1.3	
Empennage L/E (Nr. 4) Transport S/M + H/C (707/KC-135)	1370	10850	92996	5355	684	16870	68	3.9	.5	12
Empennage L/E (Nr. 5) Cargo - Transport S/M - B/U	82	648	5173	295	421	1805	63	3.6	5.1	22
Empennage L/E (Nr. 6) Cargo S/M + Bond	48	91	4416	279	22		92	5.8	2.2	
Empennage L/E (Nr. 7) Cargo S/M - Bond	68	146	6256	394	73		92	5.8	1.0	
Wing L/E (Nr. 8) Transport (AMST) H/C Bond	1020			7190	3408			7.0	3.3	
Wing T/E (Nr. 9) Transport (AMST) H/C Bond	545			3000	497			5.5	.9	

C. Control Surfaces

Eight structures (Table C.V) were analyzed as typical of control surfaces which included spoilers, flaps, rudders, elevators, and ailerons. Control surfaces were generally the least costly of the secondary structures, ranging from 1.0 to 4.6 man-hours/lb. Since these components did not offer the potential of significant cost savings, no further discussion is provided except that assembly is again the primary cost as with other secondary structures. These parts are simple assemblies compared to other secondary structures, and thus result in lower costs.

D. Air Ducts and Tail Cones

Six air duct and tail cone type structes (Table C.VI) were examined in this cost study with all being high cost components in man-hours per pound. The man-hours/lb ranged from 3.0 to 6.5. These structures are high part components ranging from 131 parts to 875 parts for each component. Since the types of structures are very similar, the cost problems are very similar with high cost areas associated with fabrication or assembly of all of the parts involved. There were no other identifiable areas where costs could be reduced significantly.

E. Miscellanous Components

A number of the secondary structures were grouped into a miscellaneous category because data was available for only one or two of each type of component. These components are speedbrakes, canopies, fairings and wing tips and are listed in Table C.VII. Detailed, in-depth data on these components was lacking, but the costs seemed to be in the same range as other secondary structures with man-hours/lb between 1.5 and 7.3. The

Table C.V - CONTROL SURFACES

	WEIGHT	MATERIAL $	TOTAL $	MAN-HOURS	PARTS	Fast.	$/LB	MH/LB	PARTS /LB	Fast. /LB
Spoiler (Nr. 1) F/A - Subsonic S/M - B/U (A-7)	11.3	95	1259	52	19	30	111	4.6	1.0	3
T.E. Flap (Nr. 2) F/A - Subsonic S/M - B/U (A-7)	53.2	448	5948	246	109	3400	112	4.6	2.0	64
Flap (Nr. 3) Cargo S/M - B/U	290	537	5220	302	200		18	1.0	1.0	
Rudder (Nr. 4) Small Cargo S/M - B/U	142	264	6106	377	400		43	2.7	2.8	
Elevator (Nr. 5) Small Cargo S/M - B/U	209	606	7315	430	40		35	2.1	.2	
Aileron (Nr. 6) Cargo S/M - B/U	170	450	5780	343	400		34	2.0	2.4	
Spoiler (Nr. 7) Transport H/C - Bonded (727)	46			46	147	119		1.0	3.2	2.6
T/E Flap (Nr. 8) Transport H/C - Bond (AMST)	540			1520	550	-		2.8	1.0	-
T/E Flap (Nr. 9) Transport (AMST)				38.7	8					

Table C.VI
AIR DUCTS AND TAIL CONES

	WEIGHT	MATERIAL $	TOTAL $	MAN-HOURS	PARTS	FAST.	$/LB	MH/LB	PARTS /LB	FAST. /LB
Duct Assembly (Nr. 1) F/A - Subsonic S/M - B/U (A-7)	159.7	1220	13807	557	412	5900	86	3.5	2.6	37
Tail Cone Assembly F/A - Subsonic (A-7) S/M - B/U (Nr. 2)	38.1	292	4484	189	131	3000	118	5.0	3.5	79
Tail Cone (Nr. 3) Small Cargo S/M - B/U	94	226	4512	276	150		48	3.0	.6	
Nose Cowl (Nr. 4) Transport S/M - B/U (DC-8)	161	1665	9596	517	227	1370	60	3.2	1.4	9
Air Intake Duct (F-14) F/A - Supersonic S/M - B/U (Nr. 5)	586	19500 Al,Ti,Steel	76500	3800	875	7750	130	6.5	1.5	13
Tail Cone (Nr. 6) Transport F/G - B/U (C-141)	36	675	1690	108	195	-	47	3.0	5.4	-

Figure C.4 - CONTROL SURFACE Nr. 1

SPOILER ASSEMBLY
FIGHTER / ATTACK - SUBSONIC

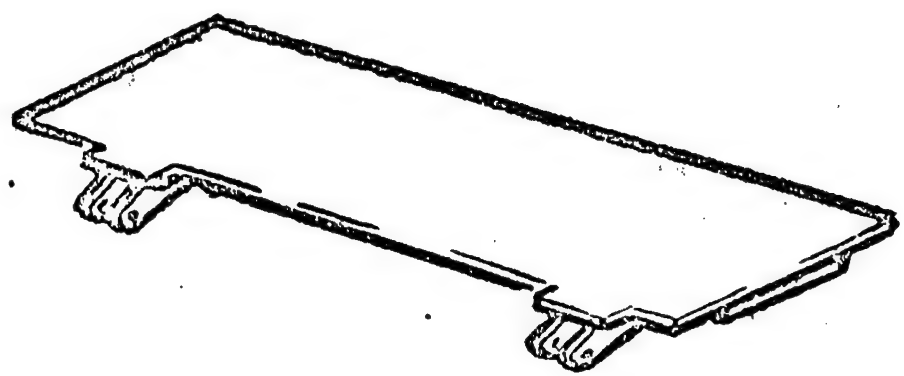


Figure C.5 - Control Surface Nr. 1

SPOILER ASSEMBLY - EXPLODED SECTION

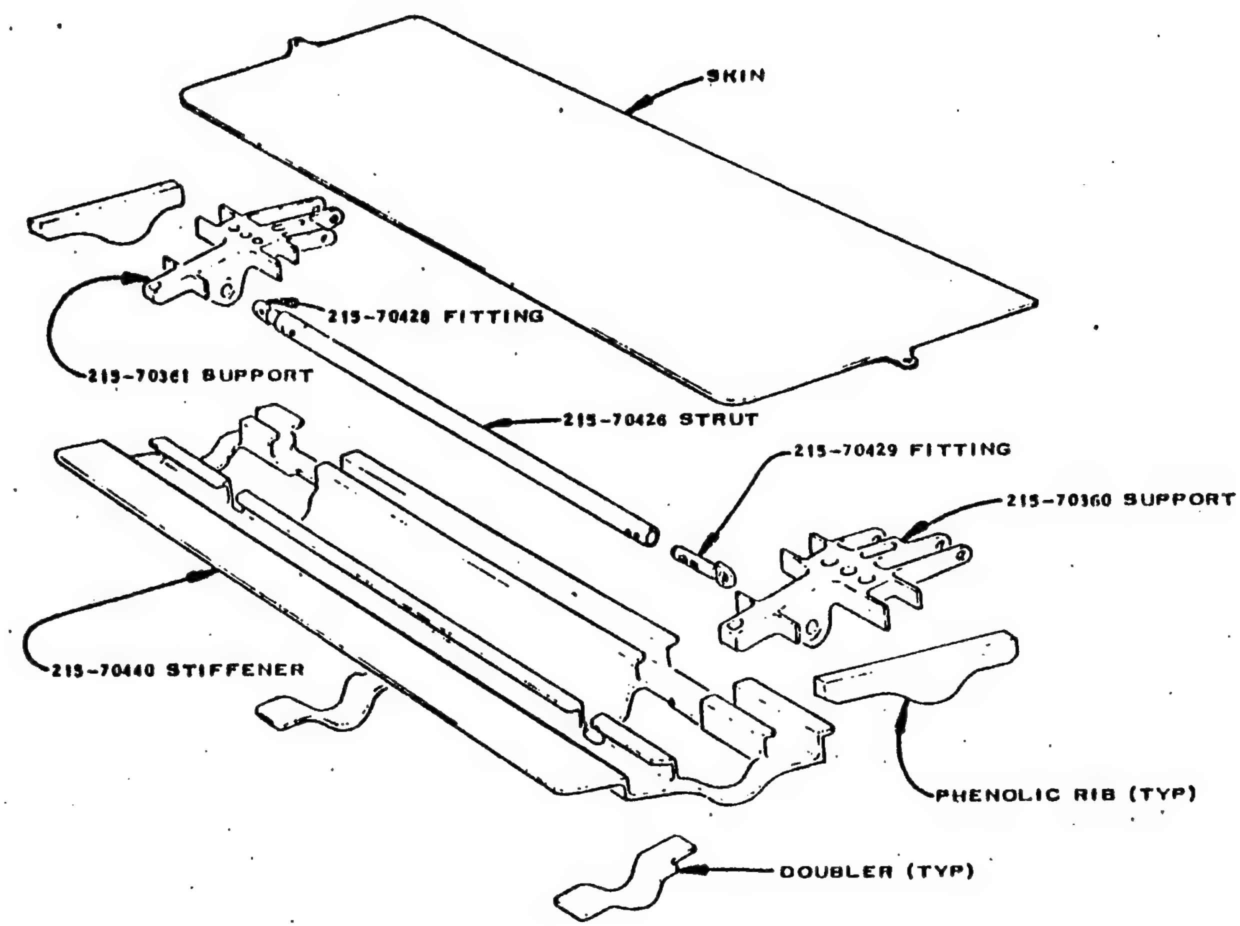


Figure C.6 - CONTROL SURFACE Nr. 2

TRAILING EDGE FLAP ASSEMBLY
FIGHTER / ATTACK - SUBSONIC

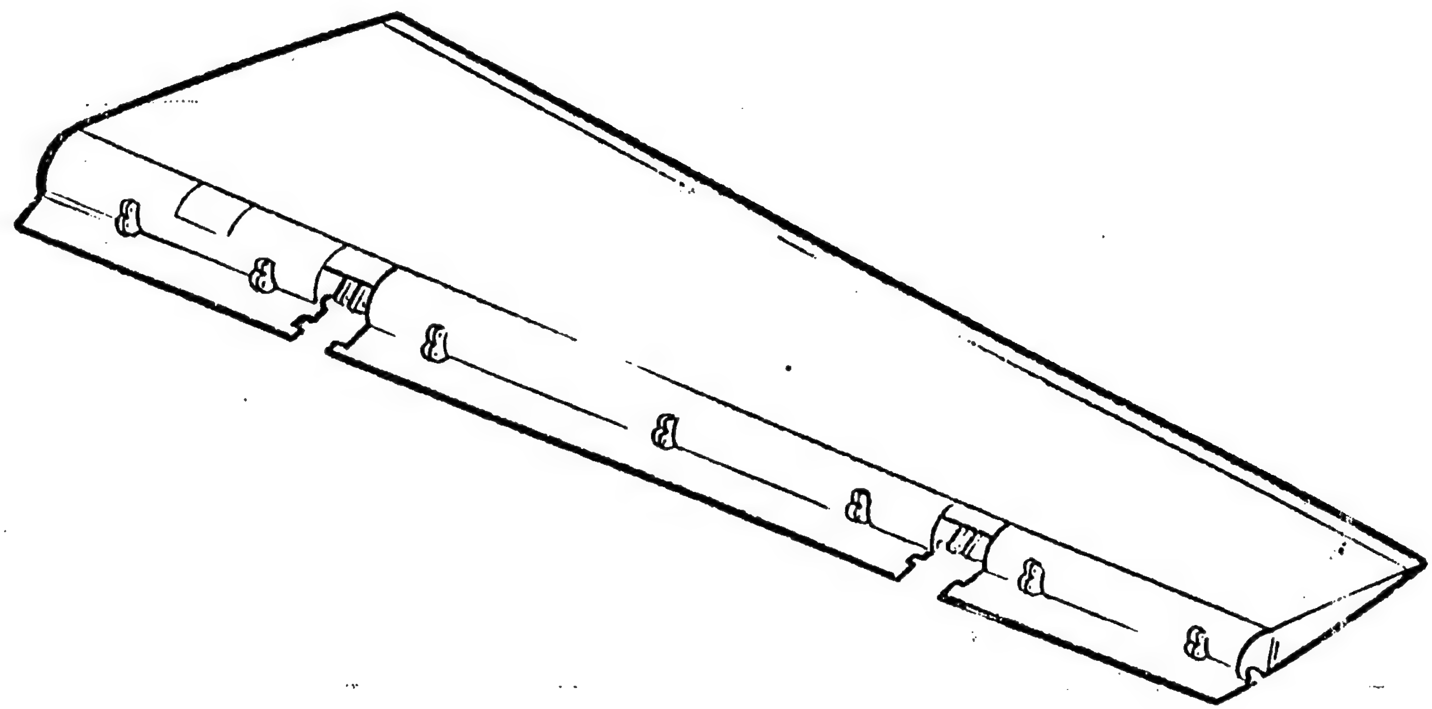


Figure C.7 - CONTROL SURFACE Nr. 2

TRAILING EDGE FLAP ASSEMBLY
- EXPLODED SECTION

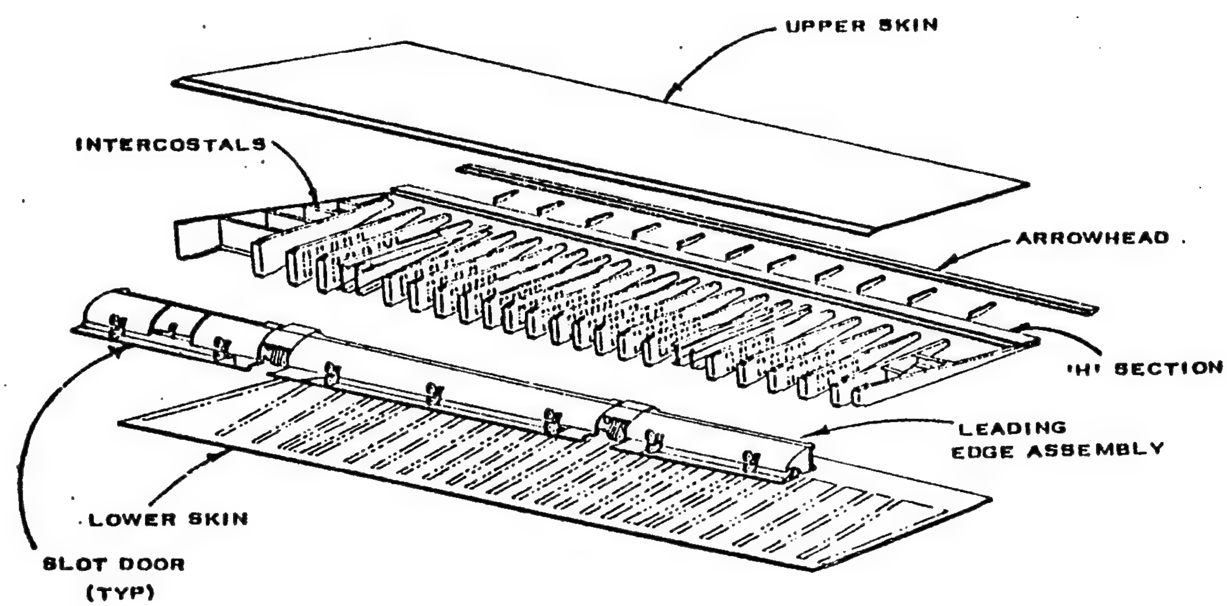


Figure C.8 - AIR DUCT/TAIL CONE Nr. 1

FORWARD DUCT ASSEMBLY
FIGHTER ATTACK - SUBSONIC

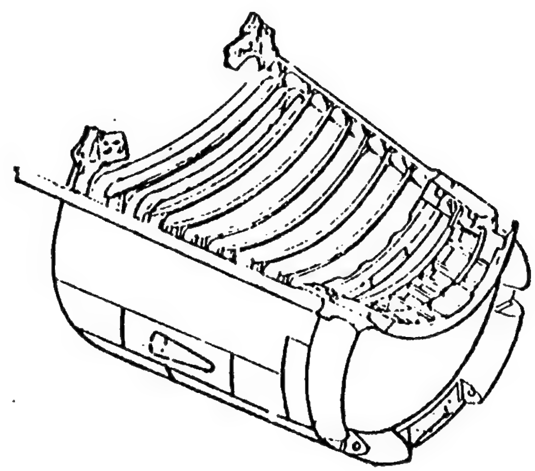


Figure C.9 - AIR DUCT/TAIL CONE NR. 1

FORWARD DUCT ASSEMBLY - EXPLODED SECTION

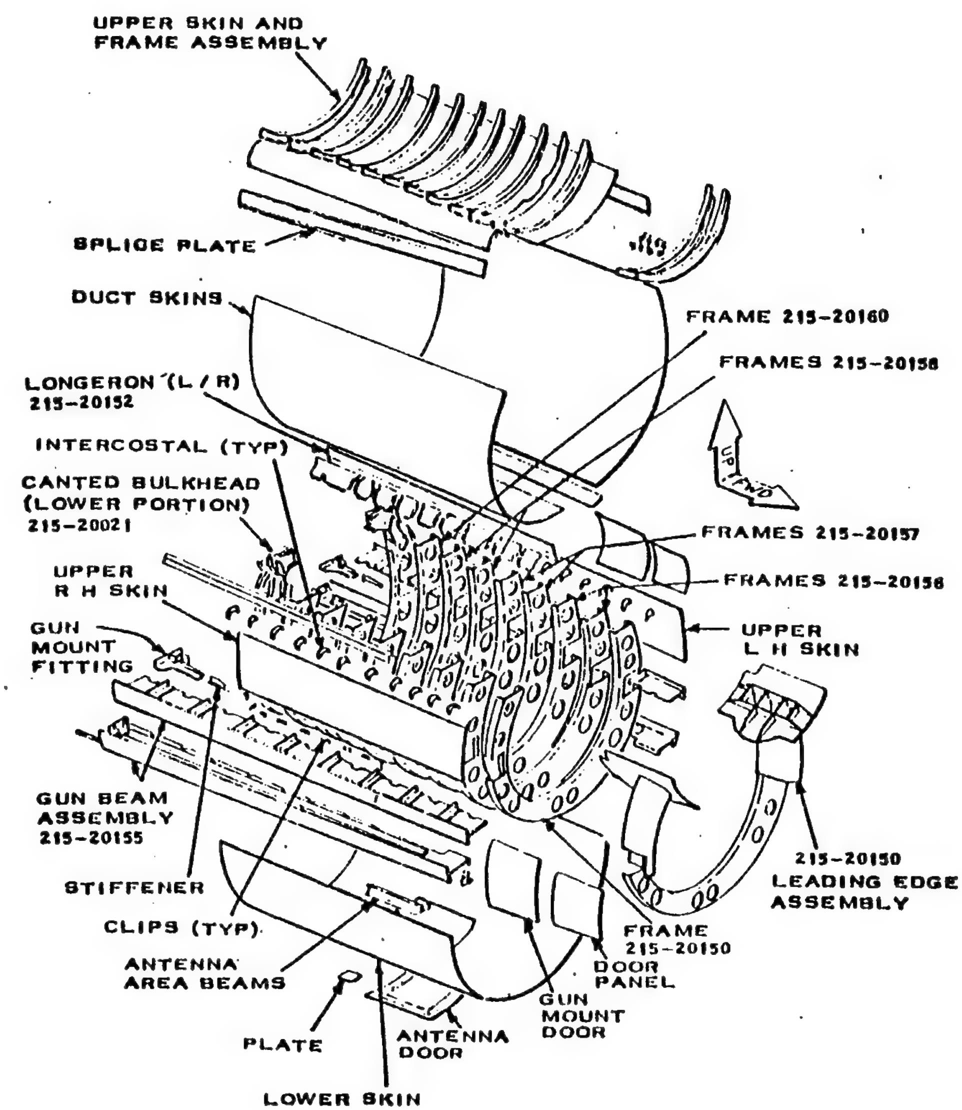


Figure C.10 - AIR DUCT/TAIL CONE Nr. 2

TAIL CONE ASSEMBLY
FIGHTER/ATTACK-SUBSONIC

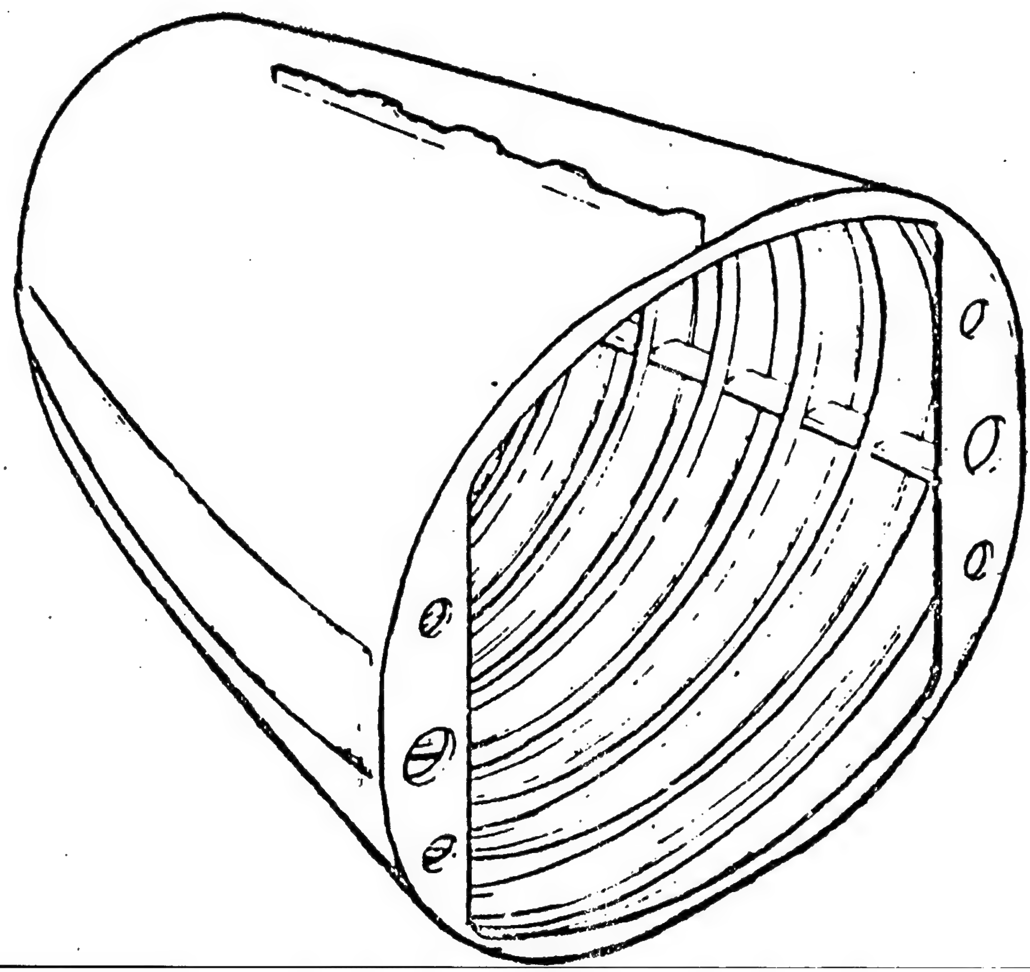


Figure C.11 - AIR DUCT/TAIL CONE Nr. 2

TAIL CONE ASSEMBLY-EXPLODED SECTION

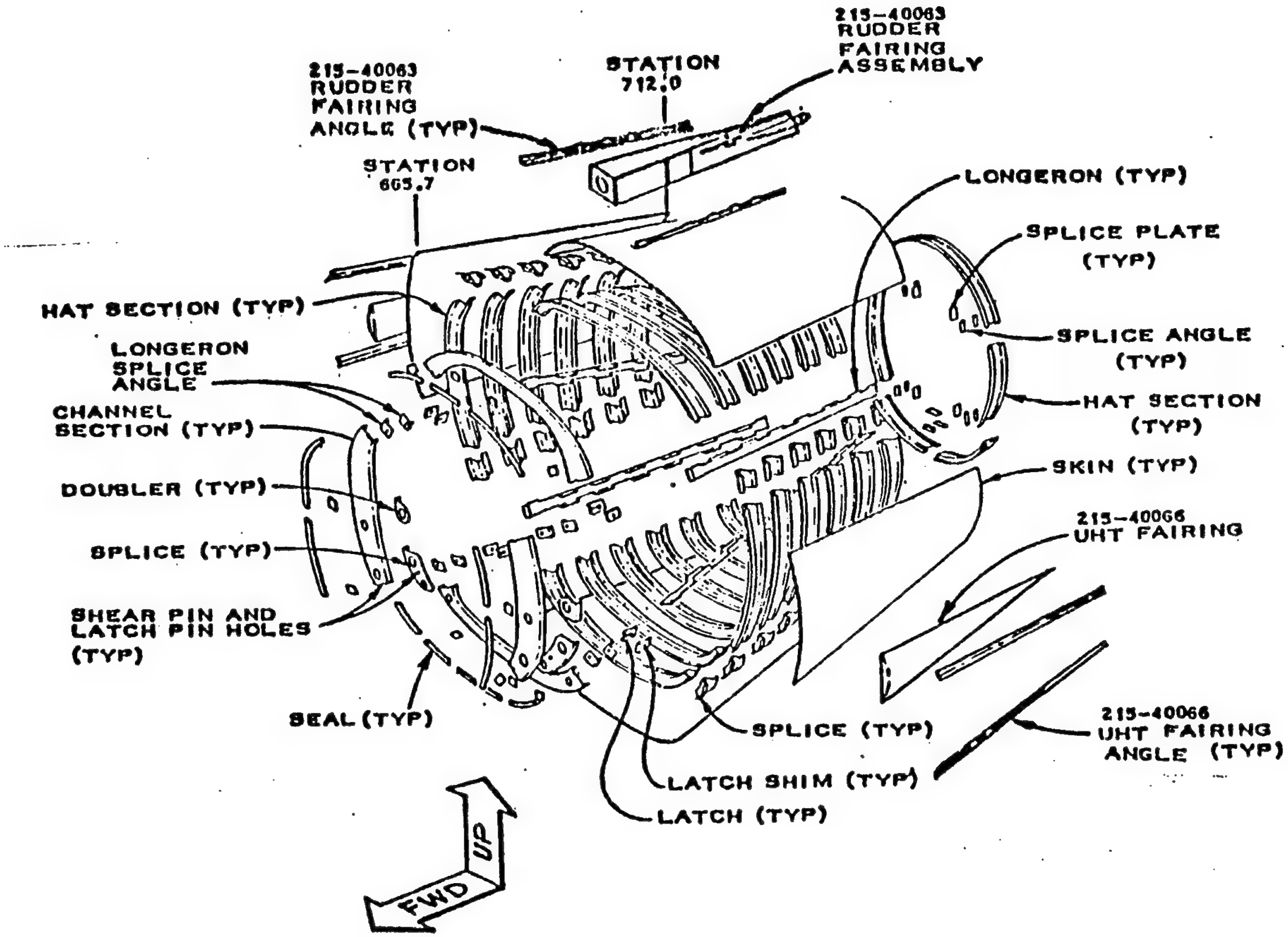


TABLE C.VII - MISCELLANEOUS COMPONENTS

	WEIGHT	MATERIAL $	TOTAL $	MAN-HOURS	PARTS	FAST.	$/LB	MH/LB	PARTS /LB	FAST. /LB
Speedbrake (Nr. 1) F/A - Subsonic S/M - B/U	135.3	1034	7207	260	264	3500	53	1.9	2.0	26
Canopy (Nr. 2) F/A - Supersonic Casting	150	8390	10865	225	99	-	72	1.5	.7	-
Canopy (Nr. 3) F/A Subsonic S/M - B/U	170	1600	15,250	900	400		90	5.3	2.4	
Wing Body Fairing Transport F/G (Nr. 4)	1900			4180	714			2.2	.4	
Wing Tip (Nr. 5) Small Cargo S/M - B/U	63	112	3654	222	300		58	3.6	.2	
Wing Tips (Nr. 6) Transport F/G	37	252	4660	270			126	7.3		

Figure C.12 MISCELLANEOUS COMPONENT Nr. 1

SPEED BRAKE ASSEMBLY
FIGHTER/ATTACK-SUBSONIC

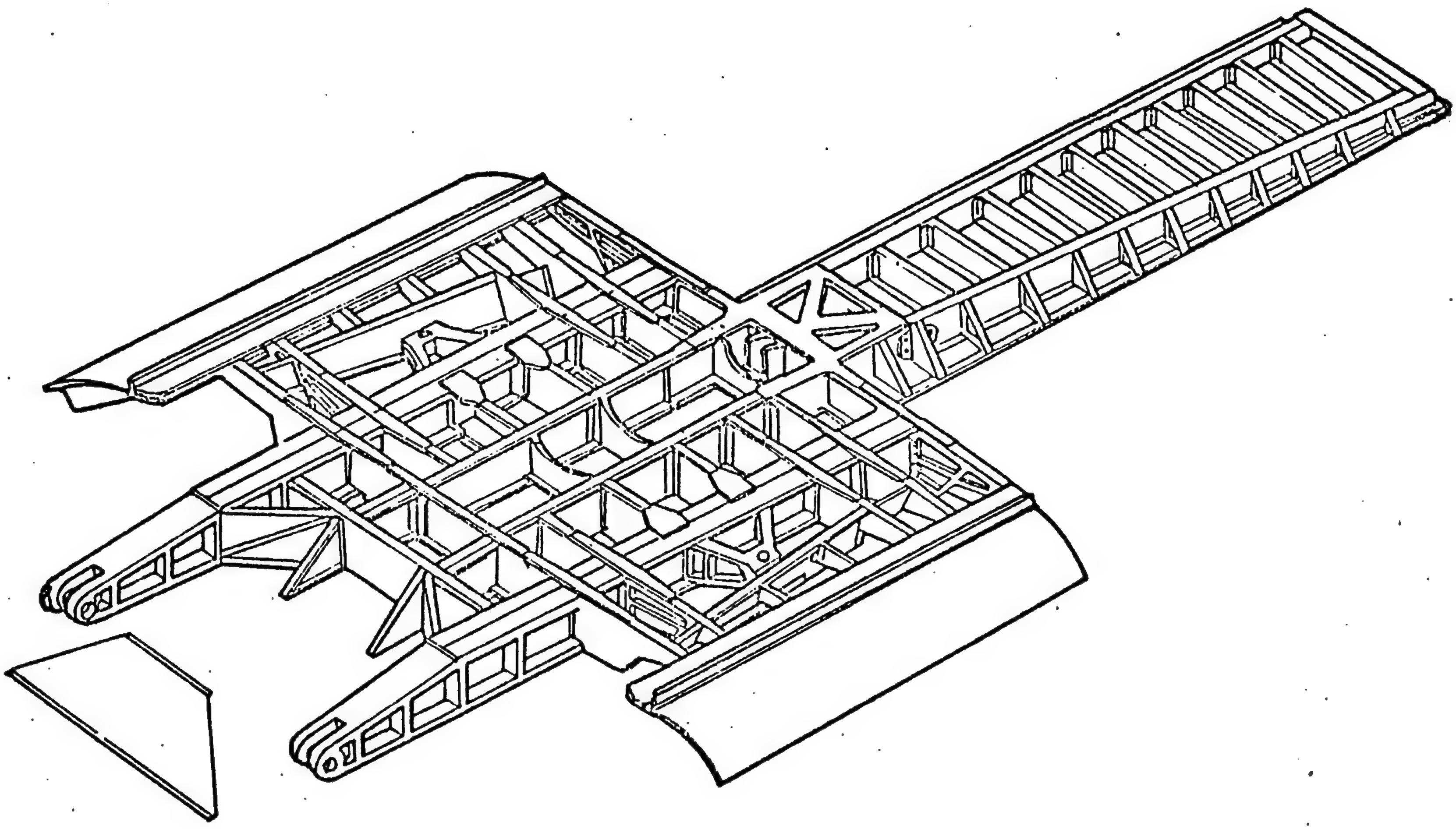
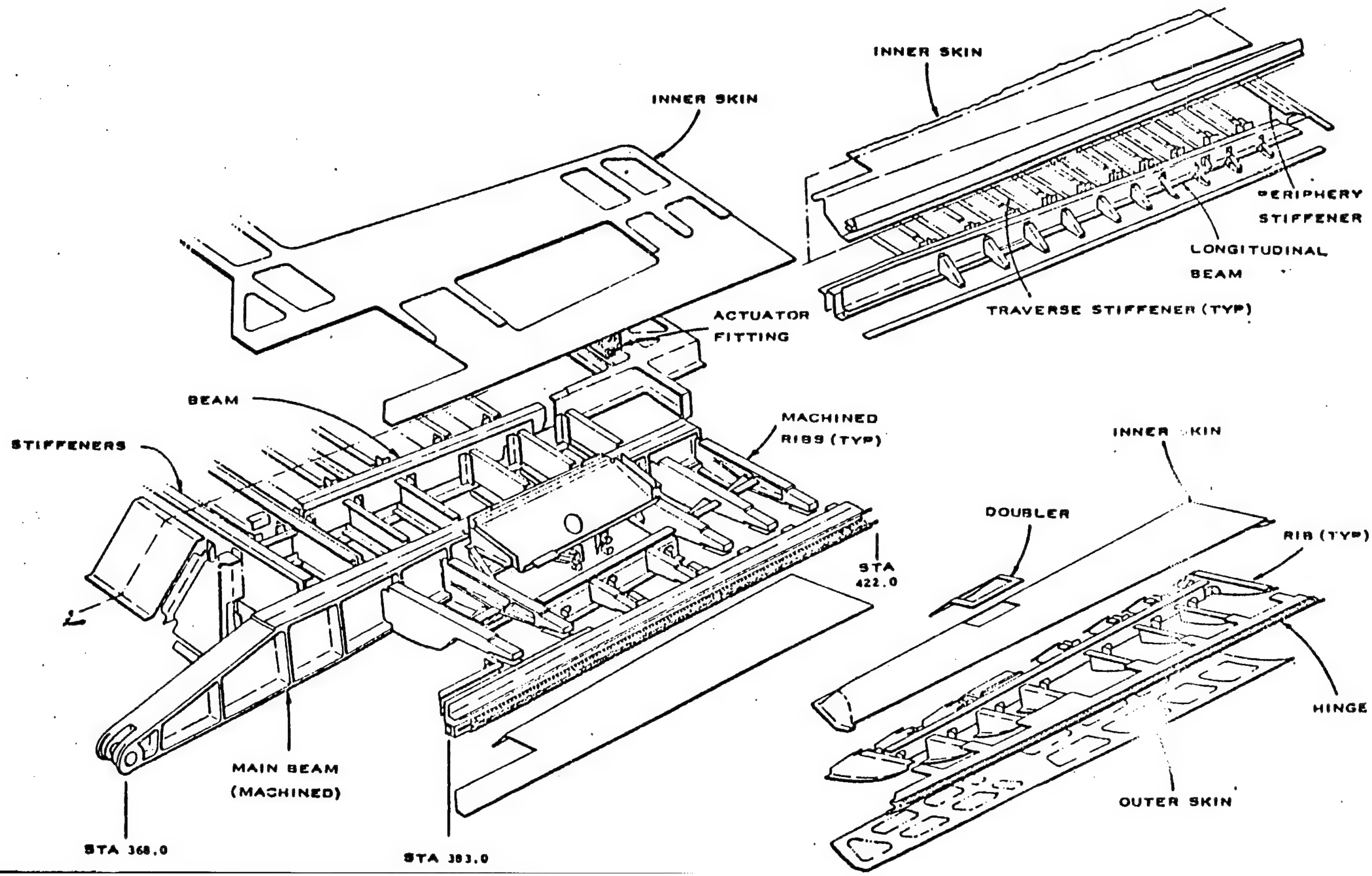


Figure C.13 - MISCELLANOUS COMPONENT Nr. 1

SPEED BRAKE ASSEMBLY-EXPLODED SECTION



1.5 man-hour/lb value was for a canopy component in which a large casting had been used, thus reducing fabrication hours in comparison with many small pieces normally involved with this type of component. The casting approach increased the material cost for the canopy from the 10% range to 80% of the total cost; however, because of decreased fabrication costs, the canopy cost per pound with the casting was only $72/lb as compared to the sheet-metal, built-up canopy at $90/lb. An obvious conclusion, therefore, is that a reduction in number of parts and reduced assembly cost can be achieved for some of the secondary structures by the use of castings. The casting in this case reduced the number of parts considerably; with the subsonic fighter/attack canopy fabricated by sheet-metal, build-up having 400 parts, while the supersonic fighter/attack canopy with the casting has only 99 parts. Lower cost joining methods and reduction in number of parts are the other two conclusions drawn from the analysis of these components.

F. Installations

Since it became obvious from the analyses performed that installations were extremely important cost area in airframe fabrication, investigation of these costs was accomplished in addition to the five areas previously discussed; However, these were a late addition and little data were available. A very brief investigation of fabrication and assembly of electrical wiring, hydraulic tubing and pneumatic ducting of all types (Table C.VIII), showed that a large number of man-hours were involved for both the hydraulic tubing and the electrical wiring (i.e. 14,037 man-hours). Not only were the hours high, but the man-hours per pound were 3.1 and 10.4 respectively

TABLE C.VIII - INSTALLATIONS

	WEIGHT	MATERIAL $	TOTAL $	MAN-HOURS	PARTS	RIVETS	$/LB	MH/LB	PARTS /LB	RIVETS /LB
Electrical Wiring all Types (Nr. 1) Fab-Assembly	1354			14,037				10.4		
Hydraulic Tubing all Types (Nr. 2) Fab-Assembly	1433			4412				3.1		
Pneumatic Ducting all Types Alum. Weldments	32			127				4.0		

with assembly-installation cost of these parts being almost the entire cost; thus this is an area where the Air Force should give serious cost reduction consideration.

G. Cost Analysis

In the above secondary structure cost analysis areas man-hours/lb was used as the important cost analysis factor with 3.0 considered as the value at which the MH/LB cost became too high. This was an arbitrary cost value selected by the panel. In Figure C.14 a plot of MH/LB vs Parts/LB reflect the majority of secondary structures with values above the 3.0 level. It was also concluded that too many parts were involved when over 2.0 parts/lb were required. For example, referral is made to the two canopy values in Figure C.14. The one in the high cost area (6.0 MH/lb is the one with 400 parts and a high $/lb while the low value in MH/LB is also very low in parts/lb. This is because the canopy with a casting replaces many of the small parts.

Figure C.15 shows Cost Analysis - Number of Rivets which again shows that most of the secondary structures plotted are above 3.0 MH/LB. It also shows that the number of rivets/lb for the parts plotted is typically over 20 with the spoiler as an exception; but this component is not primarily a riveted assembly in contrast to most secondary structures.

Based on Figures C.14 and C.15, 3.0 MH/LB was chosen as the highest desired value for use in this analysis with any value over this considered as a high cost component and subsequently analyzed for cost reduction. Any value under 3.0 was considered as inexpensive and examined to see why

Figure C.14

COST ANALYSIS
NUMBER OF PARTS

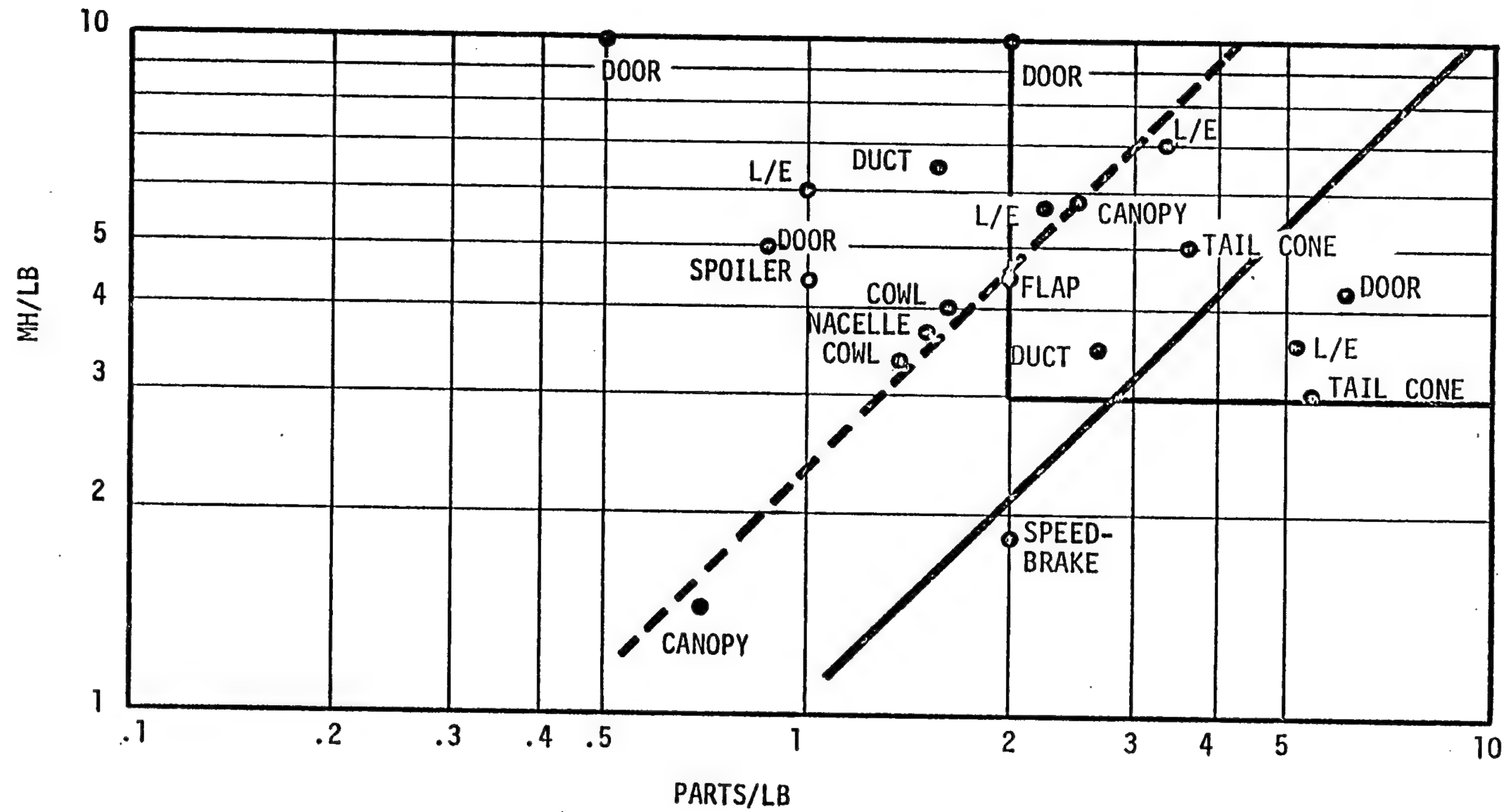
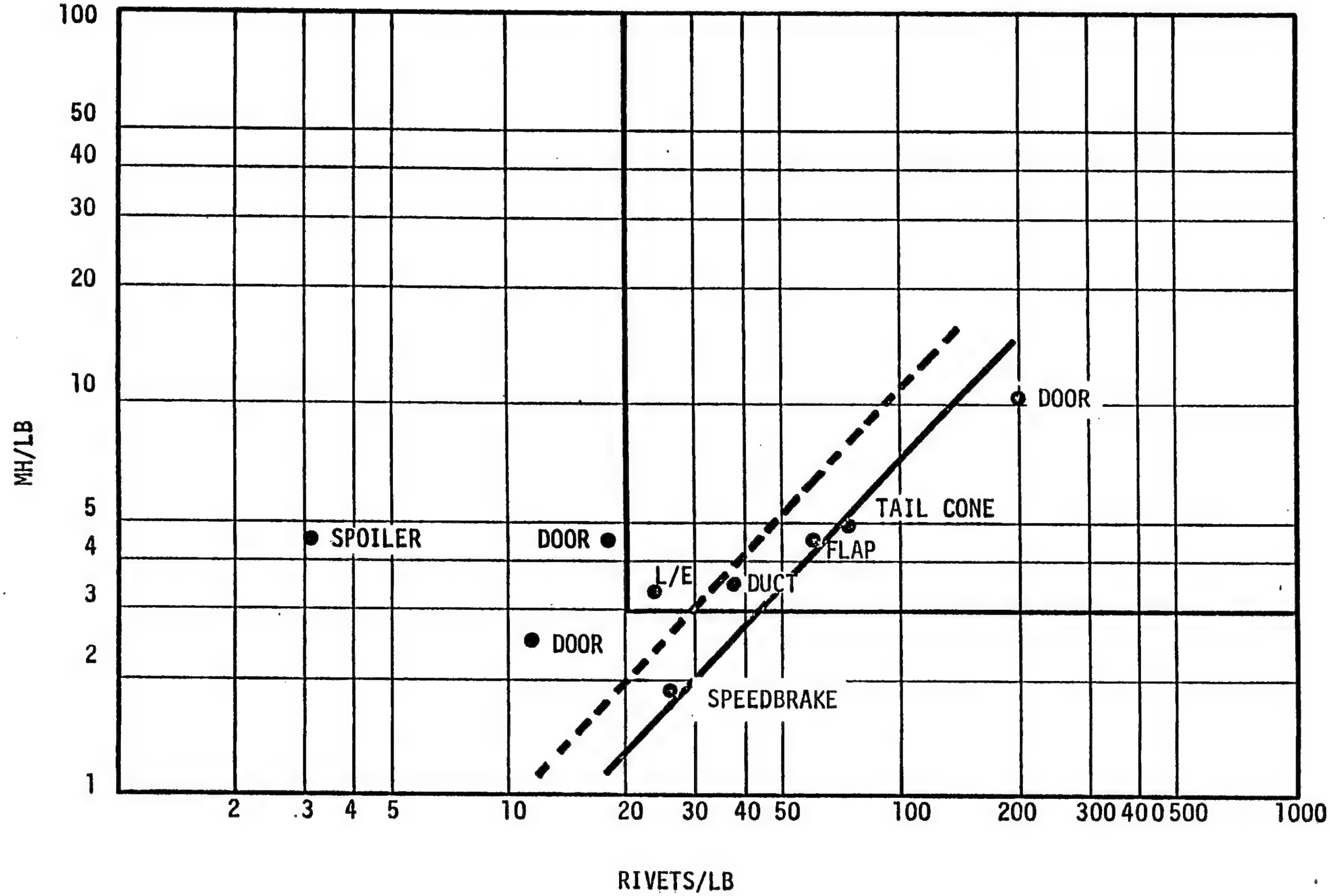


Figure C.15

COST ANALYSIS
NUMBER OF RIVETS



it was so inexpensive and also if the same approach could be applied to other secondary structures. These general conclusions are based on this above analysis, with all Operation Sheets and operation cost data used in the detailed analysis contained in Section V of this report.

IV. RECOMMENDATION CHARTS

It became very obvious early in the study that the general problem with secondary structures was the high cost associated with a large number of parts and assembly of these parts. Therefore, in considering recommendations to reduce costs of these structures by 20% or more, technology areas were examined that could reduce the number of parts, joining costs, and other related costs. Other areas considered were reducing material costs for some high cost applications with special emphasis placed on installation costs and titanium sandwich construction. Titanium sandwich is a material with interesting promise for several secondary structures, but presently has a very high cost.

The Cost Reduction Study performed by this panel has resulted in the identification of ten technology areas where further development is needed to reduce the cost of Secondary Structures. These ten areas are:

- Mechanical Fastening Systems
- Hydraulics Installation
- Actuators and Valves
- Electrical Wires
- Bonding
- Castings
- Titanium Tubing
- Titanium Sheet Metal Fabrication
- Titanium Sandwich Structures
- Weldbonding

The following paragraphs contain a summary discussion and listing of important factors for each of the above areas. Since the purpose of this study was to identify additional developments needed to reduce the cost of structures, it was thought that these items should have additional discussion. Therefore, each item is summarized with some discussion as to why the developments are necessary, followed by a listing of significant facts. This listing presents the factors under the following headings:

REFERENCE: This item includes the secondary structures this technology area could be applied in order to reduce costs. Following the listed components are reference numbers to the data sheets in Section V that indicate this problem area.

CURRENT FABRICATION PROBLEMS: This identifies the problems that now exist and are causing the high costs.

STATE-OF-ART: This considers where we are now in order to determine what work needs to be done.

ADDITIONAL DEVELOPMENT: Listed here are the developments needed before this technology can see broad usage in reducing the cost of secondary structures where it is applicable.

A. Mechanical Fastening Systems

Design data is needed to define and understand the stress field around interference fit holes and cold-worked holes, and subsequently how these hole treatments effect fatigue life and corrosion resistance

performance. A quick release fastener for use in load carrying applications would be useful to make "secondary structures" perform as load carrying structures. An NDI method is needed for inspecting under the heads and at interfaces of installed fasteners since the removal of an interference fastener for inspecting the hole often damages the hole or degrades the structure. The development program on nitinol material for fasteners should be continued as an approach for less costly interference fit fasteners.

MECHANICAL FASTENER SYSTEMS LISTING

REFERENCE:
- Leading Edges (Leading Edge 4 & 5)
- Nacelle Inlet (Door 3, Air Duct 3)
- Access Doors (Door 2,6)
- Speed Brake (Miscellaneous 1)

CURRENT FABRICATION PROBLEMS:
- Too Many Threaded Parts
- Hole Preparation
- Inspection
- Drilling Time
- Drill Life
- Sealing

STATE-OF-THE-ART:
- Many Fastener Types and Installation Techniques
- Limited Removal Techniques
- Limited Ultrasonic Drilling

ADDITIONAL DEVELOPMENT:
- Design Data for Installed Fasteners
- Quick Release Structural Fasteners
- NDI for Installed Fastener
- Nitinol Material for Interference Fasteners

B. Hydraulic Installation

The efforts needed to reduce the costs of hydraulic tubing installations are basically self-explanatory with lower cost and easier joining techniques needed; such as, adhesive bonding, brazing and welding of aluminum. Investigation is needed to develop size reduction techniques for steel and titanium for in-place joining which would reduce man-hours for installing tubing, taking it out, working it and re-installing etc. Also, new techniques must be developed to obtain smaller forming radii for both steel and titanium tubing.

HYDRAULIC INSTALLATION LISTING

REFERENCES:
Installations of Hydraulic & Pneumatic Lines (Installation 2 & 3)

CURRENT FABRICATION PROBLEMS:
Bend Radii Limitations
Limited Joining Techniques
Repairability Limits

STATE-OF-THE-ART:
Limited Forming of Steel & Titanium
Space Limitations on In-place Joining of Steel & Titanium
Mechanical Joining of Aluminum

ADDITIONAL DEVELOPMENT:
Adhesive Bonding of Aluminum
Brazing of Aluminum
Welding of Aluminum
Tube Sizing for Steel & Titanium In-place Joining
Forming Radii for Steel & Titanium

C. Actuator and Valve Fabrication

In examining some of the secondary structures it was recognized that a high cost area existed for actuators and valves that were attached to these structures. These costs were not evident in the cost analyses, but were understood by the panel to be high cost units as they require a

considerable amount of expensive machining. Therefore, it is recommended that body blank fabrication methods such as powder metallurgy, precision forging, high integrity casting or isothermal forging be considered to reduce expensive machining costs.

ACTUATOR AND VALVE FABRICATION LISTING

REFERENCE:

CURRENT FABRICATION PROBLEMS:
- Excessive Man-Hours in Machining

STATE-OF-THE-ART:
- Actuator and Valve Forged Housings Machined Internally and Externally

ADDITIONAL DEVELOPMENT:
- Body Blank Fabrication Methods
- Powder Metallurgy
- Precision Forging
- High Integrity Casting
- Isothermal Forging

D. Electrical Wire

This item is not a metal fabrication problem, but a recognized, very high cost, installation problem; therefore, recommendations for development are included for consideration by the Electronics Branch of the Manufacturing Technology Division. It is believed that flat wire concepts could be used for connector cost reduction, light-weight transition splices, modification and repair techniques and improved structure penetration and installation techniques. Flexible printed circuits have seen some use, but a Design Data Handbook would assure greater acceptance and utilization of this technique. Multiplexing is a new area that has seen limited application. One suggested extention of using this technology would be its application to signal systems.

ELECTRICAL WIRE LISTING

REFERENCE:
Installation-Electric Wire (Installation 1)

CURRENT FABRICATION PROBLEMS:
Man-Hours for Installation
Weight
Space

STATE-OF-THE-ART:
Flat Wire - Space & Missile Use Only
Flexible Printed Circuits - Minor Use in Black Boxes
Multiplexing - Limited Application

ADDITIONAL DEVELOPMENTS:
Flat Wire - Connectors
Light-weight Transition Splices
Modification and Repair Techniques
Structure Penetration and Installation Techniques
Flexible Printed Circuits - Develop Design Handbook Data
Multiplexing - Expand Application to Signal Systems

E. Bonding

Current bonding systems are faced with ecology problems related to surface preparation methods, therefore, non-polluting systems must be developed to allow bonding to achieve greater use in cost reduction of secondary structure assembly. A room temperature, low pressure (vacuum) adhesive system will reduce man-hours involved in bonding and thus make it an even more attractive joining technique. Compatibility of a corrosion inhibiting primer system with spotwelding (i.e. weldbonding) or another corrosion inhibiting technique is necessary before spotweld/bonding will be used extensively. A bond strength NDI method for metal & non-metal assemblies will greatly reduce in-process inspection costs (such as coupons) and increase confidence in the bonding process and thereby the application of bonding to all types of structures.

BONDING LISTING

REFERENCE:

Control Surface (Control Surface 7,8)
- Spoilers
- Flaps
- Leading Edges (Leading Edge 6 to 9)

Doors (Door 4 to 9)
- Actuated
- Non/Actuated

CURRENT FABRICATION PROCESS:

68% Man-hours (Control Surface 7)
- Cure and Clean
- Core Density
- High Temperature

STATE-OF-THE-ART:

Aluminum Systems

ADDITIONAL DEVELOPMENTS:

Aluminum and High Temperature
- Non-polluting
- Room Temperature Cure
- With Spotwelds
- Low Pressure
- NDI-Bond Strength
- Improved Fatigue
- Improved corrosion resistance in long time stressed environment

F. Casting

Castings are a natural solution for reduction in part fabrication costs and joining of the parts; however, size limitations and lack of confidence are limiting the use of castings. Additional development is needed to establish mechanical property data for aluminum castings for canopies and spoilers, with improved surface finish needed before they are widely accepted. Repairability and NDT techniques, if developed would add to the overall confidence and subsequently their acceptance. Baseline data must be developed for titanium castings before they will find wide

usage. Weldability developments are needed to increase the usage of castings. Finally, there is a need for improvements in the high temperature properties of castings.

CASTING LISTING

REFERENCE:
- Canopies - Aluminum (Miscellaneous 2,3)
- Spoilers - Aluminum (Control Surfaces 1,2,3,7,8)
- Trailing Edge Flaps - Aluminum
- Fittings - Titanium
- Elbows - Titanium
- Crank Assembly - Titanium

CURRENT FABRICATION PROBLEMS:
- Number of Parts in S/M-B.U.
- Assembly Man-hours
- Machining Man-hours
- Titanium Scrap

STATE-OF-THE-ART:
- Size Limitations
- Low Confidence
- Limited Shapes and Thicknesses
- Titanium Infancy Stage

ADDITIONAL DEVELOPMENTS:
- Mechanical Property Data
- Improved Surface Finish
- Repairability and NDT
- Baseline Data for Ti Castings
- Weldability
- High Temperature Properties
- High Reliability (repeatable properties)

G. Titanium Tubing

Currently most major aerospace companies have their own material specifications for tubing which result in additional planning, control, inspection and other efforts. Since these efforts contribute directly to the high cost of the product, standardization of these specifications would result in a direct cost reduction The present variety of wall

thicknesses ordered require special production runs with tooling, set-up costs, and waste material during change-over, thus again increasing the cost of finished tubing. It is recommended that some agreement be reached that would allow a reduction in the number of required wall thicknesses. In addition it is recommended that the inner and outer tube surface finish requirements be standardized. In the standardization of specifications, consideration should be given to tubing only in the recrystallized, annealed condition as most companies are utilizing this material. Processing of the finished tubing to the same mechanical property requirements simplifies production, production planning, control and contributes to price reduction. In addition to the above, the panel feels that some product quality improvement can be accomplished through burst test requirements and standardization of sampling and resampling plans for destructive tests. Burst tests would give information about texture and circumferential elongation that is not presently being obtained.

TITANIUM (Ti-3Al-2.5V) TUBING LISTING

REFERENCE:
- Hydraulic Systems
- Environmental Systems

CURRENT FABRICATION PROBLEMS:
- Uncoordinated Industry Specs
- Lack of Standardization
- Excessive Testing (Q.A.)

STATE-OF-THE-ART:
- Only Ti-3Al-2.5V Available
- Ti-6Al-4V Not Available

ADDITIONAL DEVELOPMENT:
- Introduce Burst Test Requirement to Specification
- Standardize Material Condition, Tube Size and Finish

H. Titanium Sheet Metal Fabrication

Problems in friction sawing, chem-blanking (waste material), drilling, and in obtaining complex shapes limit titanium use and increase the cost through increased man-hours and scrap material. It is, therefore, recommended that laser technology be expanded for sharp contours and complex configurations to reduce cutting costs. Ultrasonics should be used with drilling to countersink and drill through thicker sheet material in order to reduce high drilling costs. Forming concepts, such as superplasticity, should be developed further to reduce scrap material and obtain the capability for making more complex shapes without expensive machining.

TITANIUM SHEET METAL FABRICATION LISTING

REFERENCE:
- High Temperature Nacelles (Air Ducts & Tail Cones 5)
- Fuselage Body Panels
- Bulkhead Attachments

CURRENT FABRICATION PROBLEMS:
- Friction Sawing(Man-hours)
- Chem-Blanking (Titanium Waste)
- Drilling (Man-Hours)
- Complex Shapes (Bend Radii)

STATE-OF-THE-ART:
- Laser Cutting
- Ultrasonic Drilling

ADDITIONAL DEVELOPMENTS:
- Expand Laser Technology for Sharp Contours and Complex Configurations
- Expand Ultrasonics for Countersinking and Drill Gages .090"
- Superplasticity
- Tapered Rolled Sheet

I. Titanium Sandwich Structure

This type of material is being used in almost every new system being built even though the cost is extremely high both in material and fabrication cost. Several developments must be realized in order to reduce costs and increase use of the material including development in formability, edge treatments, tooling concepts, joining techniques and NDI. Comprehensive design allowables are also needed. Engineering design guides are needed to provide the design engineer with the data required for utilizing the material. It also appears that for some sandwich structures, costs can be reduced by a rolling program to achieve lower cost thin sheet over 36 inches wide.

TITANIUM SANDWICH STRUCTURE LISTING

REFERENCE:
- Shrouds and Fairings (Miscellaneous 5)
- Inlet Ducts (Air Duct 2.5)
- Control Surfaces (Door 1,2,3,7,8; Control Surface 1,2; Leading Edge 8,9)
- Engine Components (Cases, Ducts, Blades, Thrust Reversers)

CURRENT FABRICATION PROBLEMS:
- High Part Count (Joints)
- High Fastener Count

STATE-OF-THE-ART:
- Limited Mainly to Prototypes & High Temperature Applications
- Limited Engineering and Manufacturing Allowables Data
- Relatively High Cost for Secondary Applications

ADDITIONAL DEVELOPMENT:
- Comprehensive Allowables
- Engineering and Manufacturing Data
  - Formability
  - Edge Treatments
  - Tooling Concepts
  - Joining Techniques
  - NDI

J. Weldboning

Weldboniding shows significant cost savings potential for fabrication c secondary structures. Cost savings can be realized from two sources: (1. replacement of mechanical fastened joints in existing designs, (2) redesign of structural components utilizing weldbonding.

Weldbonding may be used on a large number of secondary structures if the following developments are made. High temperature adhesive (400°F and 600°F) are needed for use in supersonic aircraft components, particularly for titanium materials. Environmental fatigue and stress corrosion data are needed for design considerations in aircraft which have long life requirements (i.e. 60,000 flight hours). For applications which exceed current developments, design limits data will be required. Also, in-process inspection procedures and requirements must be established for those applications (e.g. materials, adhesives, thicknesses, adherend thickness ratios in joints, etc.) which exceed those being established on current development programs.

WELDBONDING LISTING

REFERENCES:

- Wing Tips (Miscellaneous 7)
- Spoilers (Control Surface 1)
- Trailing Edge Flaps (Control Surface 2)
- Actuated Door (Doors 8)
- Access Door (Doors 2)
- Wing Leading Edge and Trailing Edge (Leading Edge 1,4, and 4)

CURRENT FABRICATION PROBLEMS:

- Assembly Man-Hours are high for more commonly used joining methods
- Too Many Parts, Fasteners and Joints
- Limited to Low Temperature Applications

STATE OF-THE-ART:
- Limited to Sub-Sonic Applications
- In-Service Data Limited
- Production Confidence Needed

ADDITIONAL DEVELOPMENTS:
- High Temperature Adhesives, 400°F & 600°F
- Environmental Fatigue & Stress Corrosion Data
- Capability Handbook for Applications Beyond Current Development Programs
- In-Process Inspection Requirements Beyond Current Development Programs

V. Supporting Operation Sheets

The following pages contain detailed tabular data on secondary structure components that were comprehensively examined. This data was utilized in formulating the Tables in Section III of this panel report. Each Table contains data on a single component in the Section III Tables.

TABLE C.IX. DOOR DR.1 OPERATION SHEET

EQUIPMENT ACCESS DOOR
FIGHTER/ATTACH - SUBSONIC

WORK AREA	OPERATION	NO. OF PARTS	M/H
PART BLANKS	B/F CLIPS PROFILED DOUBLER C/M SKIN S/F FRAME R/F FRAMES R/F STIFFENERS	13 1 1 1 3 6	1 1/2
FORMING	S/F FRAME R/F FRAMES/STIFFENERS B/F CLIPS	1 9 13	7
MACHINING	PROFILED DOUBLER C/M SKIN	1 1	1/2
HAND WORK	R/F FRAMES/STIFFENERS S/F FRAME B/F CLIPS	9 1 13	1
SUB-ASSEMBLY	ASSEMBLE, DRILL, DISASSEMBLE - SEAL/ SPOT WELD SKIN/EDGE MEMBERS		6
FINAL ASSEMBLY	ASSEMBLY, RIVET	100 Rivets	2
INSPECTION	10% PRODUCTION		2
PROCESSING	10% PRODUCTION		2
TOTAL			20

TABLE C.X. DOOR NR. 2 - OPERATION SHEET

SUPERSONIC F/A
FUSELAGE ACCESS PANEL

WORK AREA	OPERATION	NO. OF PARTS	M/H	%
DETAIL FAB.	S/M Beaded Panel, Forming	2	6.3	16.5
BONDING	Etch, Prime, Lay-up Bag, Autoclave, De-Bag		5.0 8.0	13.2 21.1
MECH. FASTENING	Clean, Drill, Rivet	132 Rivets	17.0	45.0
FINISH	Paint & U.S. Inspection		1.6	4.2
TOTAL			37.9	100

TABLE C.XI DOOR Nr. 3 - OPERATION SHEET

SUBSONIC NACELLES

WORK AREA	OPERATION	NO. OF PARTS	M/H	%
FABRICATION	DETAILS	2562	1743	25.4
MACHINE	DETAILS		99	1.4
SUB/ASSY	ADH. BOND		727	10.6
	MECH ASSY		345	5.0
MAJOR ASSY	ASSEMBLE, DRILL, BURR INSTALL FITTINGS, FASTENER	14880	2050	29.9
MISC.			445	6.5
INSPECTION			757	11.0
PROCESSING			695	10.2
TOTAL			6861	100

TABLE C.XII. - DOOR NR. 4 - OPERATION SHEET

PRESS. DOOR-TRANSPORT
BONDED HONEYCOMB

WORK AREA	OPERATION	NO. OF PARTS	M/H	%
FABRICATION	Shear & Form Face Sheets, Clean Parts. Machine H/C Core, Exgernal Reinforcing Stiffeners, and Hinge Fittings		138	28.8
SUB-ASSEMBLY	Bond & Cure H/C Door Segments, Trim Segments for Final Assembly Fit-up		134	28.0
ASSEMBLY	Load Door Segments Into Final Assembly Tool. Drill & Pot Holes for External Stiffeners and Hinge Fittings. Drill Holes, Deburr, & Install Fasteners in Segment Splices, Install External Stiffeners and Hinge Fittings. Install Door Edge Seal & Apply Prime Finish.		164	34
INSPECTION	Visual, Ultrasonics, and Pressure Test		44	9.2
TOTAL		123	480	100.0

TABLE C.XIII. - DOOR NR. 5 - OPERATION SHEET

MAIN LANDING GEAR DOORS
TRANSPORT
FULL SEPTH HONEYCOMB

WORK AREA	OPERATION	NO. OF PARTS	M/H	%
FABRICATION	Shear & Form Face Sheets, Machine close out Members, Machine H/C Core, & Clean Parts for Bonding		380	34.8
ASSEMBLY	Load Details Into Bonding Assembly. Bond & Cure Assembly. Drill & Pot Holes for Hinge and Actuator Fittings. Install Fittings. Install Door Seal & Apply Prime Finish		610	55.8
INSPECTION	Visual Inspect & Ultrasonically Inspect		102	9.4
TOTAL			1092	100

TABLE C.XIV - DOOR NR. 6 OPERATION SHEET

SUPERSONIC DOOR
NON ACTUATED

WORK AREA	OPERATION	NO. OF PARTS	M/H	%
FABRICATION	DETAILS		64	14.9
MACHINE	MACHINING	352	11	2.6
SUB/ASSY.	ADH. BOND MECH. ASSY		73	17.0
MAJOR ASSY.	ASSEMBLE, DRILL, BURR INSTAL SEALS.	1800 RIVETS	246	57.3
MISC.			6	1.4
INSPECTION			12	2.8
PROCESSING				
TOTAL			430	100

TABLE C.XV. - DOOR NR. 7 - OPERATION SHEET

SUPERSONIC F/A
MAIN LANDING GEAR DOOR

WORK AREA	OPERATIONS	NO. OF PARTS	M/H	%
DETAILS	Forming (4 skins, 26 edge members	30	30	6.3
	Chem-mill skins (6 steps)		50	10.4
Core Details	Machining	31	40	8.2
Hinge Fittings	Machining	2	30	6.3
Actuator Fitting	Machining (Titanium)	1	50	10.4
ASSEMBLY	Finish Core to Fit Contour Fit Edge Members Bond Skins, Core, & Eges with Fittings Seal Edge Member Joints		280	58.4
TOTAL			480	100

TABLE C.XVI - DOOR NR. 8 - OPERATION SHEET

DOORS ACTUATED
SUPERSONIC-TI H/C SANDWICH

WORK AREA	OPERATION	NO OF PARTS	M/H	%
FAB MACHINING	DETAIL FORMING, TRIM, & HT	78	70 8	13.0 1.5
SUB/ASSY	ADH. BOND SUB ASSY		32 178	5.9 32.9
MAJOR ASSY	ASSEMBLY, DRILL, BURR RIVET, INSTALL SEALS	645 FASTENERS	200	37.0
MISC.	CLIPS, SHIMS, ETC.		2	.4
INSPECTION			30	5.6
PROCESSING			20	3.7
TOTAL			540	100

TABLE C.XVII - DOOR NR. 9 - OPERATION SHEET

SUBSONIC
COWL PANELS

WORK AREA	OPERATION	NO. OF PARTS	M/H	%
FABRICATION	DETAILS	488	296	27.4
MACHINE	DETAILS		10	.9
SUB/ASSY	ADH. BOND MECH ASSY		238 48	22.0 4.4
MAJOR ASSY	ASSEMBLE, DRILL, BURR AND INSTALL FASTENERS	4130	124	11.6
MISC.			81	7.5
INSPECTION			116	10.7
PROCESSING			168	15.5
TOTAL			1081	100

TABLE C.XVIII. OTHER DOORS - OPERATION SHEET

WORK AREA	OPERATION	NO. OF HRS	M/H	%
56# ACESS DOOR	Built-up Sheet Metal			
SHT METQL		.85	47.5	62.5
MACH. PTS		.27	15.1	21.5
ASSEMBLY		.14	7.8	16.0
		1.26	70.4	100
68# MLG. DOOR	Built-up Sheet Metal			
DETAIL FAB		1.32	90.1	74.8
ASSEMBLY		.45	30.6	25.2
		1.77	120.7	100
22# SPEED BRAKE	Built-up Mach. Parts & Sheet Metal Parts			
DETAIL FAB		2.40	53.0	39.4
ASSEMBLY		3.80	81.5	60.6
		6.20	134.5	100

TABLE C. XIX - FIXED EDGE NR. 1 - OPERATION SHEET

WING LEADING EDGES
TRANSPORT
BUILT-UP STRUCTURE

WORK AREA	OPERATION	NO. OF PARTS	M/H	%
FABRICATION	Shear, Hydro Press Form Sheet Metal Details. Perform Minor Hand Form Operations. Machine Fittings		1570	35.3
ASSEMBLY	Load Details Into Final Assembly Tool. Drill & Deburr Detailed Parts. Install Fasteners. Apply Prime Finish		2210	49.7
INSPECTION	Visual Inspect During and After Assembly		670	15.0
TOTAL			4450	100

TABLE C.XX - FIXED EDGE NR. 2 OPERATION SHEET

SUB-SONIC - SMALL CARGO
WING-FIXED L.E.

Total Weight: 1800# INBD-CENTER-OUTBD

WORK AREA	OPERATION	NO. OF PARTS	M/HR	%
FAB. SHEET METAL MACHINING	Shear, Route, Form & Process	Fab	1,000	45.0
SUB. ASSY	Riveted Frame Sub Assembly	1.23 MH/LB Sub	155	2.1
ASSEMBLY	Drill-Countersink-Burr-Rivet	Assy	1,065	47.9
TOTAL		951	2,220	100

TABLE C.XXI - FIXED EDGE NR 3 - OPERATION SHEET

SUB-SONIC - SMALL CARGO
WING-FIXED T.E.

Total Weight: 531#

WORK AREA	OPERATION	NO. OF PARTS	M/HR	%
FAB. SHEET METAL MACHINING	Shear - Route - Form Mill Std. Al. Cuts		450	42.3
SUB-ASSY	Rivet Sub Assy Frame	2.02 MH/LB	288	27.1
ASSEMBLY	Drill, Countersink, Burr & Rivet		324	30.6
TOTAL		400	1,062	100

TABLE C.XXII - FIXED EDGE NR. 4 - OPERATION SHEET

SUBSONIC EMPENNAGE
L.E. - TRANSPORT

WORK AREA	OPERATION	NO. OF PARTS	M/H
FAB	Details	684	961
Machine			137
SUB/ASSY	ADH' BOND		1235
	MECH. ASSY		141
MAJOR ASSY	Assemble Drill, Burr Install Fasteners	16870	1647
MISC			549
INSPECTION			411
PROCESSING			274
		TOTAL	5355

TABLE C.XXIII FIXED EDGE NR. 5 - OPERATION SHEET

SUBSONIC
EMP. LEADING EDGE

WORK AREA	OPERATION	NO. OF PARTS	M/HR
FABRICATION	DETAILS	421	60
SUB/ASSY			17
MAJOR ASSY	ASSEMBLE, DRILL BURR C/SINK INSTAL FASTENERS.	1805	151
MISC			17
INSPECTION			34
PROCESSING			16
TOTAL			295

TABLE C.XXIV. FIXED EDGE NR. 6 - OPERATION SHEET

SUB SONIC - SMALL CARGO

EMPENNAGE-VERT. L/E (HEATED)

Total Weight: 48#

WORK AREA	OPERATION	NR. OF PARTS	M/HR	%
FAB. SHEET METAL MACHINING	Shear, Route, Form & Process Std. Al. Milling		15	5.5
SUB ASSY.	Bond Lay-up & Rib Sub Assy	5.8 MH/LB	97	34.7
ASSEMBLY	Load Bond Fixture - Cure-Trim		167	59.8
TOTAL		22	279	100

TABLE C.XXV - FIXED EDGE NR. 7 - OPERATION SHEET

SUB SONIC - SMALL CARGO

EMPENNAGE-HORIZ L/E (HEATED)

Total Weight: 68#

WORK AREA	OPERATION	NR. OF PARTS	M/HR	%
FAB. SHEET METAL MACHINING	Shear-Route-Form & Process Std. Alum. Milling		29	7.3
SUB ASSEMBLY	Plastic Sub Assembly of Ribs	5.8 MH/LB	103	26.2
ASSEMBLY	Layup-Cure-Skins Rib Assembly & Heater Element - Trim & Drill Inspect		262	66.5
TOTAL		73	394	100

TABLE C.XXVI - FIXED EDGE NR. 10 - OPERATION SHEET

TAILING EDGE ASSY

TRANSPORT

WORK AREA	OPERATION	NR. OF PARTS	M/H	%
BONDING	Prefit Clean Apply Adhesive Prepare for Cure Cure	Skins 6 Doublers 2 Wdge 2 Core 1 Rub strip 3 Splice 4 Spar 1	48.4	74
MACHINE	Core Details		10.0	15
MSC.	Apply Protective Paper Seal Assy		7.6	11
TOTAL			66	100

TABLE C.XXVII - CONTROL SURFACE NR. 1 - OPERATION SHEET

SPOILER ASSEMBLY
FIGHTER/ATTACK - SUBSONIC

WORK AREA	OPERATION	NO. OF PARTS	M/H
PART BLANKS	MACHINED SUPPORTS MACHINED RIBS PROFILED SKIN R/F DOUBLERS	2 2 1 2	3
FORMING	R/F DOUBLERS	2	1/2
MACHINING	SUPPORTS ROD ENDS RIBS STRUT PROFILE SKIN C/M STIFFENER	2 2 2 1 1 1	40 1/2
HAND WORK	TRIM/DEBURR R/F DOUBLERS	9 2	1
SUB-ASSEMBLY	ASSEMBLE/BOLT STRUT/SUPPORT ASSEMBLY - DRILL/RIVET STIFFENER ASSEMBLY		3
FINAL ASSEMBLY	ASSEMBLE, DRILL/RIVET		4
INSPECTION	10% PRODUCTION		5
PROCESSING	10% PRODUCTION		5
TOTAL			62

TABLE C.XXVIII - CONTROL SURFACE NR. 2 - OPERATION SHEET

TRAILING EDGE FLAP ASSEMBLY
FIGHTER/ATTACK - SUBSONIC

WORK AREA	OPERATION	NO. OF PARTS	M/H
PART BLANKS	R/F RIBS R/F INTERCOSTALS R/F L.E. SKINS C/M UPPER SKIN C/M LOWER SKIN	44 6 8 1 1	20
FORMING	R/F RIBS R/F INTERCOSTALS R/F L.E. SKINS	44 6 8	50
MACHINING	RIBS ACTUATOR/T.E. FITTINGS SPARS C/E SKINS	4 3 2 2	20
HANDWORK	R/F PARTS	58	10
MISCELLANEOUS	B/F CLIPS, BRACKETS, ANGLES	75	6
FINAL ASSEMBLY	ASSEMBLY, DRILL DEBURR & RIVET SUBSTRUCTURE - INSTALL, TRIM, DRILL, C/S & RIVET SKINS	3400 Rivets	140
INSPECTION	10% PRODUCTION		25
PROCESSING	10% PRODUCTION		25
TOTAL			296

TABLE C.XXIX - CONTROL SURFACE NR. 3 - OPERATION SHEET

SUB-SONIC-SMALL CARGO

FLAPS

Total Weight: 290#

WORK AREA	OPERATION	NR. OF PARTS	M/HR	%
FAB. SHEET METAL MACHINING	Shear, Route, Form & Process Std. Alum. Milling		125	41.4
SUB ASSEMBLY	Rivet Frame Sub Assy.		26	8.6
ASSEMBLY	Drill, Countersink, Burr Rivet		151	50.0
TOTAL		200	302	100

TABLE C.XXX - CONTROL SURFACE NR. 4 - OPERATION SHEET

SUB SONIC - SMALL CARGO

RUDDER

Total Weight: 142

WORK AREA	OPERATION	NR. OF PARTS	M/HR	%
FAB. SHEET METAL MACHINING	Shear, Route, Form & Process Std, Alum. Milling		29 76	7.7 20.0
SUB ASSEMBLY	Plastic Sub Assembly Layup		48	12.8
ASSEMBLY	Drill, Countersink, Burr & Rivet	2.65 MH/LB	224	59.5
TOTAL		400	377	100

TABLE C.XXXI CONTROL SURFACE NR. 5 - OPERATION SHEET

SUB-SONIC-SMALL CARGO

ELEVATORS

Total Weight: 209#

WORK AREA	OPERATION	NR. OF PARTS	M/HR	%
FAB SHEET METAL MACHINE	Shear, Route, Form & Process St. Alum. Milling	Fab	180	41.8
SUB ASSEMBLY	Rivet Frame Assy.	Sub Assy	56	13.1
ASSEMBLY	Drill, Countersink, Burr & Rivet	2.07 MH/LB	194	45.1
TOTAL		40	430	100

TABLE C.XXXII - CONTROL SURFACE NR. 6 - OPERATION SHEET

SUB-SONIC-SMALL CARGO

ALLERON

WORK AREA	OPERATION	NR. OF PARTS	M/HR	%
FAB. SHEET METAL MACHINING	Standard Shear, Route & Form Extrusion & Hinge Machining		152	443
SUB ASSEMBLY	Rivet Sheet Metal Assy.		30	8.7
ASSEMBLY	Drill, Countersink, Burr & Rivet		161	47.0
TOTAL		400	343	100

TABLE C.XXXIII- CONTROL SURFACE NR. 7 - OPERATION SHEET

SPOILER
TRANSPORT AL HONEYCOMB

Total Weight: 46#

WORK AREA	OPERATION	NR. OF PARTS	M/HR	%
MACHINING	Core Details	(1) Spar (3) Cores (2) Skins (7) Doublers (1) Shim	10.1	21
BONDING	Prefit Cleaning Apply Adhesive Cure Post Clean		31.5	68
MISC	Protective Coat Install Seals Seal	(118) Bolts (6) Seals (3) Mach Fittings (6) Misc (tags etc)	5.1	11
TOTAL		147	46	100

TABLE C. XXXIV - CONTROL SURFACE NR 9 - OPERATION SHEET

TRAILING EDGE FLAP
TRANSPORT

WORK AREA	OPERATION	NR OF PARTS	M/HR	%
BONDING	Prefit Clean Mask Apply Adhesive Cure Assy	Skins 2 Beam 1 Core 1 Filler 4	27	71
MACHINING	Core Details		2.9	7
MSC.	Seal Etc.		8.7	22
TOTAL		8	38.7	100

TABLE C.XXXV - OTHER CONTROL SURFACES - OPERATION SHEET

WORK AREA	OPERATION	HRS/LB	M/HR	%
738# FLAPS				
SHT. METAL	Cast L.E. Beam, Machined Ribs,	.10	73.8	6.2
MACHINE PTS	S/M Skins & Clips	1.00	738.0	61.4
ASSEMBLY		.53	390.0	32.4
		1.63	1201.8	100
300# SPOILERS				
SHT. METAL	Machined Alum. Plate	.05	15.0	1.8
MACH. PTS	S/M Clips & Misc.	2.40	720.0	93.2
ASSEMBLY		.13	39.0	5.0
		2.58	774.0	100

TABLE C.XXXVIAIR DUCT AND TAIL CONE NR. 1

OPERATION SHEET - FORWARD DUCT ASSEMBLY
FIGHTER ATTACK - SUBSONIC

WORK AREA	OPERATION	NO. OF PARTS	M/H
PART BLANKS	S/F CAP STRIPS S/F SKINS R/F FRAMES CLIPS, BRACKETS, ETC.	26 6 40 112	34
FORMING	R/F FRAMES, ETC. S/F SKINS S/F CAPS D/H FORM LIPS B/F ANGLES, ETC.	40 6 26 3 112	77
MACHINING	PROFILED WEBS CAST FITTINGS	4 7	8
HANDWORK	R/F PARTS S/F PARTS	40 26	25
MISCELLANEOUS	B/F CLIPS, ETC.	300	25
SUBASSEMBLY	ASSEMBLE, DRILL, C/S DEBURR & APPLY SEALANT RIVET DETAILS	2,500 HOLES	*138
FINAL ASSEMBLY	ASSEMBLE, DRILL, C/S - S/A DEBURR & APPLY SEALANT FLUSH RIVET S/A	3,400 RIVETS	*250
INSPECTION	10% PRODUCTION		56
PROCESSING	10% PRODUCTION		56
TOTAL			669

TABLE C.XXXVII- AIR DUCT AND TAIL CONE NR. 2

OPERATION SHEET - TAIL CONE ASSEMBLY
FIGHTER/ATTACK SUBSONIC

WORK AREA	OPERATION	NO. OF PARTS	M/H
PART BLANKS	S/F SECTIONS (HATS) R/F CHANNELS R/F SPLICE DETAILS CLIPS, BRACKETS, ETC. SKINS	28 4 4 50 4	18
PREFORM	R/F HATS	28	9
FORMING	S/F HAT SECTIONS R/F CHANNELS, ETC. B/F DOUBLERS, ETC. S/F SKINS	28 40 4 4	45
MACHINING	PROFILE LONGERONS LATCH DETAILS	4 16	4
HANDWORK	S/F PARTS R/F PARTS	28 40	9
MISCELLANEOUS	B/F CLIPS, ANGLES, ETC.	50	4
FINAL ASSEMBLY	ASSEMBLE, DRILL, FRAMES, ETC. INSTALL, TRIM, MARK SKINS FOR DIMPLING REASSEMBLE SKINS DRILL, DIMPLE, RIVET	3,000 rivets	100
PROCESSING	10% OF FACTORY		19
INSPECTION	10% OF FACTORY		19
TOTAL			227

TABLE C.XXXVIII- AIR DUCT AND TAIL CONE NR. 3 - OPERATION SHEET

SUB-SONIC - SMALL CARGO

TAIL CONE-BUILT-UP STRUCTURE

WORK AREA	OPERATION	NR. OF PARTS	M/HR	%
FABRICATION SHEET METAL BUILD-UP, MACHINING	Shear, Route, Form & Process Mill Fittings		86	31.1
ASSEMBLY RIVETED	Load Jigs with Detail Parts, Drill-Countersink, Deburr, Hand Rivet Assembly		190	68.9
TOTAL		150	276	100

TABLE C.XXXIX. - AIR DUCT AND TAIL CONE NR. 4 - OPERATION SHEET

SUBSONIC
NOSE COWLS

WORK AREA	OPERATION	NR. OF PARTS	M/HR	%
FABRICATION	Details	227	150	29.0
MACHINE	Details		5	4.7
SUB ASSY	MECH ASSY		60	11.6
MAJOR ASSY	ASSEMBLY, DRILL BURR, INSTALL FITTINGS & FASTENERS	1370 RIVETS	175	33.9
MISC			30	5.8
INSPECTION			36	7.0
PROCESSING			41	8.0
TOTAL			517	100

TABLE C.XL - AIR DUCT AND TAIL CONE NR. 5 - OPERATION SHEET

SUPERSONIC F/A
ENGINE AIR INTAKE DUCT

WORK AREA	OPERATIONS	NR. OF PARTS	M/HR	%
DETAIL FAB.	Ti 6-6-2 Skins Ti & Steel Forge Bulkheads Aluminum Frames Al & Ti Longerons Stiffeners Splice Plates Intercoastals	875	1100 (detail parts)	29
MACHINING	All Ti, Steel, Al parts		1480	39
NACELLE ASSEMBLY	Load Subassembly into assembly fixture Install Longerons, Intercoastals, L.G. Drag Brace Support (locate, drill, fasten). Install inner skins (align, drill, fasten). Install outer skins (" " ").		1220	32
TOTAL		875	3,800	100

TABLE C.XLI- AIR DUCT AND TAIL CONE NR. 6 OPERATION SHEET

TAIL CONE - TRANSPORT
FIBERGLASS

WORK AREA	OPERATION	NR. OF PARTS	M/HR	%
FABRICATION	Lay-Up and Cure Fiberglass. Install metal ring in base during lay-up		33	30.5
ASSEMBLY	Drill holes in metal ring base & install anchor nuts. Cut hole in cone apex & install light reflector. Apply prime finish		60	55.6
INSPECTION	Visual inspect		15	13.9
TOTAL		195	108	100

TABLE C.XLII- MISCELLANEOUS NR. 1

OPERATION SHEET - SPEEDBRAKE
FIGHTER/ATTACK SUBSONIC

WORK AREA	OPERATION	NO. OF PARTS	M/H
PART BLANKS	S/F OUTER SKINS S/F INNER SKINS B/F INNER SKINS S/F LONGITUDINAL PARTS R/F RIBS, GUSSETS, ETC.	6 3 4 8 73	22
FORMING	S/F OUTER SKINS S/F INNER SKINS B/F INNER SKINS S/F LONGITUDINAL PARTS R/F RIBS, GUSSETS, ETC.	6 3 4 8 73	67
MACHINING	RIBS MAIN BEAMS ACTUATOR, HINGES	18 2 3	37
HANDWORK	R/F PARTS S/F PARTS	63 8	15
MISCELLANEOUS	B/F CLIPS, BRACKETS, ETC.	50	4
SUBASSEMBLY	ASSEMBLE, DRILL, RIV. FOR. & AFT. STRUCTURES A/D/R 2 CHINE STRUCTURES	1,800 rivets	69
FINAL ASSEMBLY	A/D/R 4 MAJOR STRUCTURES A/D/R INNER & OUTER SKINS	1,700 rivets	46
INSPECTION	10% PRODUCTION		26
PROCESSING	10% PRODUCTION		26
TOTAL			312

TABLE C.XLIII– MISCELLANEOUS NR. 2 and NR. 3 – OPERATION SHEET

F/A
CANOPIES (CASTING vs S/M B.U.)

WORK AREA	OPERATIONS	NR. OF PARTS	M/H	%
CASTING CONCEPT (NR. 2)				
CASTING	PURCHASED PART	99		11.3
DETAILS	SHEET STIFFENERS, SIDE RAILS, ETC.		25	
ASSEMBLY	ADD PRESSURE PANELS TO PRESSURE BULKHEADS ADD REQ. SHEET STIFFENERS ATTCH OUTSIDE SKINS TO SIDE RAILS, INSTALL GLASS & SEAL		200	88.7
			225	100
SHEET METAL, B.U. (NR. 3)		400		
DETAIL FAB	SIDE RAILS, FIBS, CLIPS FORWARD BOW REAR BOW VERT. PRESSURE BULKHEADS HORIZ PRESSURE BULKHEADS		100	11
			800	89
ASSEMBLY	JOIN SUBASSEMBLIES, INSTALL GLASS & SEAL			
			900	100

TABLE C.XLIV MISCELLANEOUS NR.5 - OPERATION SHEET

WING-TIP

Total Weight: 63#

WORK AREA	OPERATION	NR. OF PARTS	M/HR	%
FAB. SHEET METAL MACHINE	Shear, Route, Form & Process Std. Alum. Milling	Fab 3.62 MH/LB	70	31.6
SUB ASSY.	Plastic & Riveted Sheet Metal	S.A.	76.5	34.4
ASSEMBLY	Riveted Assembly	Assy.	75.5	34.0
TOTAL		300	222	100

TABLE C.XLV -INSTALLATIONS - OPERATION SHEET

WORK AREA	OPERATION	MH/LB	M/HR	%
1354# (NR.1)	ELEC. WIRING			
FABRICATION	Cut to Length, Mark Identity & Strip Ends	.59	797	5.7
ASSEMB & INST. & C/O	Install Terminals, Place on Wire Board, Install in Ship & Check out.	9.81	13,240	94.3
		10.40	14,037	100
(NR.2) 1433#	HYDRAULIC TUBING (ALUM)			
FABRICATION	Cut to Length, Mark Identity and Form.	.37	524	12
ASSEM, INST. & C/O	Assemble End Fittings, Install in ship and Pressure Check.	2.70	3888	88
		307	4412	100
(NR.3) 32#	PNEUMATIC DUCTING (ALUM WELDMENT)			
SHEET METAL ASSEM.	Trim Blank, Drop Hammer Form and Rough Trim.	.8	25.6	20
	Weld & Clean up.	3.2	101.3	80
		4.0	126.9	100

PART D

NONROTATING ENGINE COMPONENTS PANEL REPORT

I. INTRODUCTION

The nonrotating or static structures of a turbojet aircraft engine represents a significant portion of the cost associated with the procurement of engines for the U.S. Air Force. The significance of this cost is shown in Table D-I where four types of engines are compared as to the "percent of engine cost" associated with four types of nonrotating components. These components represent approximately one third to one half of the total engine cost. The requirement to examine the major elements of cost associated with their manufacture was essential in understanding how the cost of these components could be reduced.

This report is the culmination of three and one half days of effort undertaken to obtain an understanding of major cost elements in the manufacture of these types of components, and represents input from the following committee members:

Paul Hamilton - Allison
Bob Sprague - Pratt & Whitney
Bacon Yeung - General Electric
Stan Wlodek - Cabot Stellite
Chuck Mueller - Rem
Bill Koster - Metcut
Neville Edenborough - Allison
Jack Rodin - Pratt & Whitney
Reed Yount - General Electric - Chairman

This committee was assisted by Air Force personnel:

Lee Kennard - AFML
Larry Clark - AFML
Ted Norbut - AFAPL

TABLE D-I

PRIMARY NONROTATING ENGINE COMPONENTS

PERCENT OF ENGINE COST

COMPONENT GROUP	SMALL AUG. TURBOJET	AUG. TURBOJET	LOW BYPASS AUG. TURBOJET	HIGH BYPASS TURBOJET
Frames & Sumps	7.0	18.4	15.5	19.0
Casing & Ext. Hardware	7.5	16.3	10.5	14.5
Combustor Liner	3.0	.5	1.2	1.1
Aug. & Exhaust Nozzle	12.5	12.5	19.0	-
TOTALS	30.0	47.7	46.2	34.6

To obtain the results documented in this report the following "Modus Operandi" was followed:

A. Components were selected as representative of:

1. Superalloy Frames and Casings

2. Titanium Compressor Casings

3. Combustor Cans and Liners

B. Engine components of similar size and configuration were selected for detailed study from each of the three represented engine manufacturers.

C. Each component was compared by major manufacturing operation (such as machining, welding, and so forth) as to the percentage of total part cost contributed by that operation. Areas of significant cost were highlighted.

D. Finally, one component from each class - superalloy frame, compressor casing, and combustor - was selected as typical and all major cost elements from melting through final inspection were grouped into functional elements.

E. Significant elements of cost were discussed and areas for technical effort by the Air Force were recommended.

II. SUMMARY AND CONCLUSIONS

The Nonrotating Engine Components Panel selected actual production hardware items for the cost reduction study. The items selected were followed through the actual production cycle step-by-step, evaluated and compared using today's cost. The cost of each operation was identified

as a percent of the total engine cost. This method allowed an excellent exchange of information between the panel members and also provided an excellent comparison of the cost of a particular item being manufactured by three different engine companies.

The panel members reached the objectives which the Air Force outlined for them. The Air Force now has additional justification for many of their active programs in the Manufacturing Technology Area, examples of which are: Large Superalloy Castings and Titanium Scrap Reclamation. Justification is also provided for many of the FY-73 programs such as ESR Hollow Shapes and the High Temperature Combustor Program.

Pinpointing of high cost areas has also provided the Air Force with information for future "major thrust" programs which will significantly reduce end item acquisition costs. Many of the recommendations will not reduce production costs on current engines but will have an impact on future systems.

In addition to the benefits realized by the Air Force, the diverse selection of the panel provided a much needed exchange of information and philosophy between engine manufacturers, designers, raw material suppliers, quality assurance and other consultants. The exchange brought forth many problems encountered in the manufacture of components and provided further insight into the resolution of these problems.

Several significant conclusions were reached during discussion and are as follows:

A. Material removal, generally considered as turning, milling and drilling, was a significant cost center on all components studies. Raw

material was also determined to be a significant cost item on the components. Deburring and benching for fit-up were substantial cost centers on the combustors evaluated.

B. With compressor cases, raw material and metal removal in combination add to produce a large cost center. Considering the TF39 compressor casing, for example, 1,160 pounds of rough forgings of titanium 6Al-4V are ultimately reduced to a final assembly weight of 140 pounds. Original material cost in comparison to finished weight, as well as the cost of machining to remove this material, become major items in the overall cost of the part.

C. The productivity of metal removal processes (turning, milling, drilling, etc.) must be studied from all aspects in order to accomplish effective cost reduction. Conventional machine tools, typically, cut metal only 20-40% of the time a component is in the machine (machine tool utilization approaches 50% with some N/C equipment). The balance of the time, also accruing cost, is spent in set-up, tool changing, and in fixture inspection. Reduction of costs in these areas has a potential for success as great as that possible in the area of greater chip making efficiency.

D. The lack of uniformity in process and inspection standards adds appreciably to production costs at several levels. The multiplicity of specifications for nominally the same material adds to cost of production control, inspection and inventory at alloy producers. Nonstandard and noninterchangeable tapes, cutters and tooling add cost in all manufacturing areas. The nonuniformity of inspection procedures adds production

inspection and inventory expense, usually at the 2nd tier or primary subcontractor level.

E. Significant amounts of finish machining are probably being carried out to meet requirements other than those really justified by the engineering needs of the surface involved. Surface integrity considerations, for example, show that there is often considerable latitude for reducing surface finish requirements without degrading surface fatigue characteristics. Likewise, there appears to be little need for extensive hand sanding and blending of milled surfaces insofar as fatigue strength is concerned.

F. The significance of improved scrap recovery as a means of effective cost reduction has been discussed at length. The merits of recycling chips appear to be an economic balance. Extensive consideration of the recovery of nickel and cobalt from EDM sludge, however, does not appear justified at present since the total weight of metal removed by this process is small in comparison to that removed by chip making methods.

G. The quantity of a component scheduled or anticipated is the prime key to selection of cost reduction procedures. The greater the quantity to be produced, the greater the general effectiveness of a cost reduction (CR) program. Extensive CR activity in anticipation of limited production constitutes an overall waste of effort.

H. In considering cost reduction activities, it is important to differentiate between cost reduction and cost avoidance. Certain

recommendations are not suitable for components already qualified, but are intended to accomplish overall cost avoidance in future systems.

I. The current military procurement procedure lacks a means whereby those specifying the performance and other requirements of a new system under procurement can correlate the impact of features of their requests with resulting costs. Interests of material economy could be better served if a vehicle to discuss and exchange data in the performance sophistication vs cost realm could be developed within the procurement system.

III. RECOMMENDATIONS FOR AREAS OF EFFORT

The following areas of effort were identified through general discussion of the three components selected. The following recommendations are listed in order of priority with the largest percentage of cost receiving the highest priority.

A. Metal Removal

The most obvious area for cost reduction was improvement in metal removal. Listed below are several ideas to attach costs in this area.

1. Computer Aided Manufacture (CAM). To reduce the amount of non-chip making time and to improve machine utilization.

2. Better Cutting Tools or Improved Metal Removal Method. All suppliers should be requested to review present machining parameters in order to determine whether or not current machining knowledge is being

properly applied.

3. Improved Tooling or Standardized Machine Tool Adaption. In order to reduce set-up time and reduce tooling costs and inventory.

4. Improved Scrap Reclamation. This requires metal producer and user action and agreement.

B. Raw Material and Primary Working

1. Increase effort in the establishment of near net shapes. Examples are:

a. Low cost rings

b. Isothermal forgings

c. Structural castings - increased size with quality comparable to present smaller castings

d. Shaped extrusion and mill products

2. Increased utilization of ESR melting to improve forging and rolling yields. Investigation of ESR melting for production of hollow ingots to produce low cost rings.

3. Standardization of sheet metal gage thickness.

C. Quality Assurance - several items are suggested for reducing this area of cost.

1. Eliminate inspection duplication

2. Obtain specification standardization

3. Decrease the automation of inspection processes

4. Investigate low cost replacements for x-ray film

D. Hole Generation - improvement in hole drilling techniques to reduce cost are essential to combustor fabrication. Potential processes

are:

1. Laser
2. Electron Beam
3. Plasma

E. Deburring of Holes - investigate chemical, electro-chemical and abrasive methods for deburring sheet metal and fabricated components.

F. Joining - further investigation of plasma arc welding for joining of thin sheet metal components is warranted.

IV. SELECTION OF COMPONENTS

The nonrotating components of a turbojet engine represent a wide divergence in manufacturing technology. Because of the limited time allotted to this study, it was essential that the number of components be limited. In addition, since two base metals, nickel and titanium, make up the bulk of such components, it was necessary that fabrications of these two metals also be selected.

Although the nonrotating components are responsible for more than one third of the engine cost, examination of individual components will disclose that no individual component represents more than 4% of engine cost and that, in general, most complex fabricated parts do not surpass 3%. It was decided that a titanium and a nickel base component representing between 2 and 3% of the engine cost were representative and should be selected. It was also felt essential that a component representative of thin sheet metal should also be selected.

The percentage of engine cost for several engine components are shown in Table D-II. These components represent the fabrications selected for detailed cost study. These selections represented the criteria established above and were subsequently determined to be an excellent representative group.

In comparing these components with the data shown in Table D-I one obvious omission was made, a fabrication representative of an augmentor was not selected. In further discussion it was felt that combustor fabrication was to some degree representative of augmentor fabrication, but that further study in this area may be worthwhile.

V. DETAILED COMPONENT STUDY

A. Titanium Compressor Case

In examining the titanium compressor case components, a basically variable geometry configuration (TF39) and a semi-variable geometry configuration (501M62) were examined. The two types of components are shown in Figure D-1. The variable portion of the TF39 case comprised two thirds of the stages whereas for the 501M62 only one third of the stages were movable. Both types were of Ti 6 Al-4V alloy in the annealed/stress relieved condition. Both parts are fabricated by the engine manufacturer from subassemblies which are constituted by rough machining forged or rolled rings. The variable geometry configuration utilizes three rings which are subsequently joined by electron beam girth welds, whereas the 501M62 case is made from one cylindrical rough machined sleeve. Material costs are almost identical and are approximately half

TABLE D-II

NONROTATING SELECTED COMPONENTS - % OF ENGINE COST

COMPONENT GROUP	TF-39	TF-30	J-79	TF-41	T-63	F-101	501M62
Superalloy Frames & Castings							
Frame	2.8	2.5	2.0*	1.1	-	2.9*	
Casing	-	-	-	1.1*	-		
Compressor Casing	1.8	-	1.4*	1.0*	-	1.0*	2.5
Fan Casing	-	.4	-	0.9*	-	-	
Combustor Liner or Cans	1.1	.5	.5	1.2	.5	1.2	

*NOT STUDIED IN DETAIL

TABLE D-II.a

NONROTATING SELECTED COMPONENTS - COST

COMPONENT GROUP/ENGINE (Approx. Total Cost of Engine)	TF-39 700,000	TF-30 1,000,000	J-79 350,000	TF-41 460,000
Superalloy Frames & Casings				
Frame	19,600 (2.8%)	25,000 (2.5%)	7,000* (2.0%)	5,060 (1.1%)
Casing	--	--	--	5,060 (1.1%)*
Compressor Casing (Ti)	12,600 (1.8%)	--	4,900* (1.4%)	4,600* (1.0%)
Fan Casing (Ti)	--	4,000 (0.4%)	--	4,150* (0.9%)
Combustor Liner or Cans	7,680 (1.1%)	5,000 (0.5%)	1,750 (0.5%)	5,520 (1.2%)

*NOT STUDIED IN DETAIL

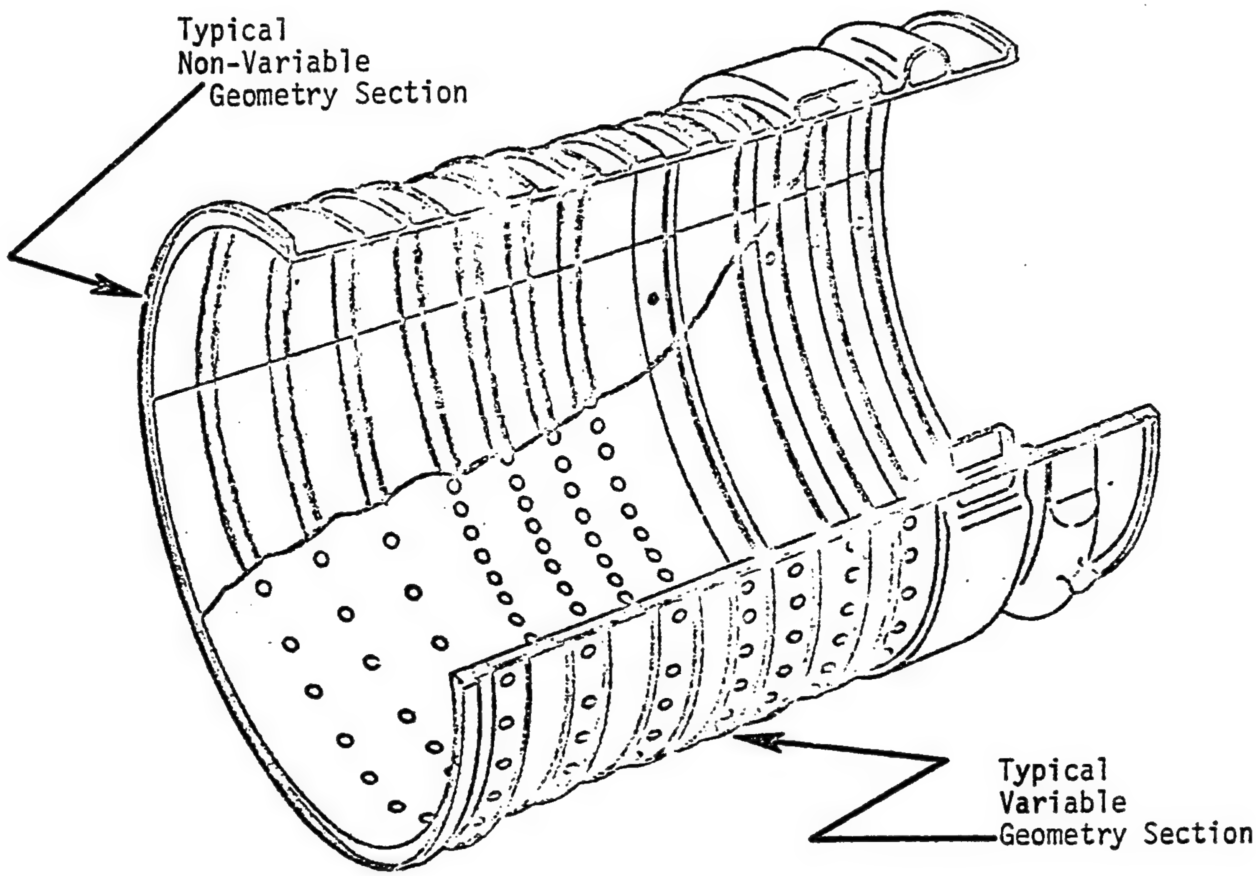


Figure D-1

TITANIUM COMPRESSOR CASES

of the total finished part cost (49 and 47 percent respectively) as shown in Table D-III. Billet to rough machined forging cost breakdown of a larger diameter, but shorter length subassembly, configured for a different sized engine and representing an intermediate compressor case design, yielded almost identical materials and operational values. Based on this fact and the comparative surface areas, it was concluded that the overall percentages developed for the two specific cases studied, probably represented a variety of sized titanium cases.

There were only two major operational percentage cost breakdown values for the two different configurations which varied significantly. In the area of drilling and reaming, there was a two-to-one greater cost for the variable design, attributed to the holes needed to accommodate the control mechanism. In addition, the method of producing holes by drilling differs from the tape mill technique used for the semi-variable case and which is also more nearly applicable to nonvariable case manufacture. The other major deviation was in the inspection/dimensional gaging regime, where there was a four-to-one greater cost to control the semi-variable case. This difference is believed to relate to the volume of production of the TF39 part which permits more sophisticated tooling and tape control checking than can be afforded for the current 501M62 production rate.

Along with the study of compressor cases, a titanium (Ti 6Al-4V) fan case for the TF30 engine was studied for comparison (see Figure D-2). This component is not welded and does not fit the manufacturing pattern of the two compressor cases. The subassembly cost for the fan case is

TABLE D-III

TITANIUM (Ti 6A1-4V) COMPRESSOR CASES COST BREAKDOWN

		% COST OF FABRICATED COMPONENT												
ENGINE MODEL	% ENGINE COST	COST OF SUBASS'Y (FORGING)	METAL REMOVAL				WELDING	NONDESTRUCTIVE TESTING/ INSPECTION	DIMENSIONAL GAGING/ INSPECTION	COATING (CLEARANCE)	BENCH OPERATIONS	HEAT TREATMENT	OTHER
			TURNING	MILLING	DRILLING & REAMING	Total							
501M62 (Semi-variable)	2.5	47.0	10.8	14.8	4.1	29.7	4.2	4.6	8.9	1.3	2.7	1.0	0.6
TF-39 (Variable)	1.8	49.0	10.0	14.6	9.1	33.7	4.5	2.0	1.7	3.3	3.8	1.4	0.6
TF30P100 (Fan Case)	0.4	56.6	53.3		8.0	43.3	-	-	-	-	-	-	0.2

TABLE D-III.a

TITANIUM COMPRESSOR CASES COST BREAKDOWN

ENGINE MODEL	COST OF CASE	% ENGINE COST	% and COST OF SUBASSEMBLY (FORGINGS)	% and COST OF METAL REMOVAL	OTHER[1]
501M62 (Semi-Variable)	*$7500	2.5	47.0/$3525	29.7/$2228	23.3/$1747
TF-39 (Variable)	$12600	1.8	49.0/$6174	33.7/$4246	17.3/$2180
TF30P100 (Fan Case)	$4000	0.4	56.6/$2264	43.3/$1732	-------

(1) Includes: welding, NDI, Dimensional Gaging, Coating, Benching, Heat Treatment

*Engine not yet in production, true cost information not available
Estimated to be 300000 class w/o controls

FOR OFFICIAL USE ONLY

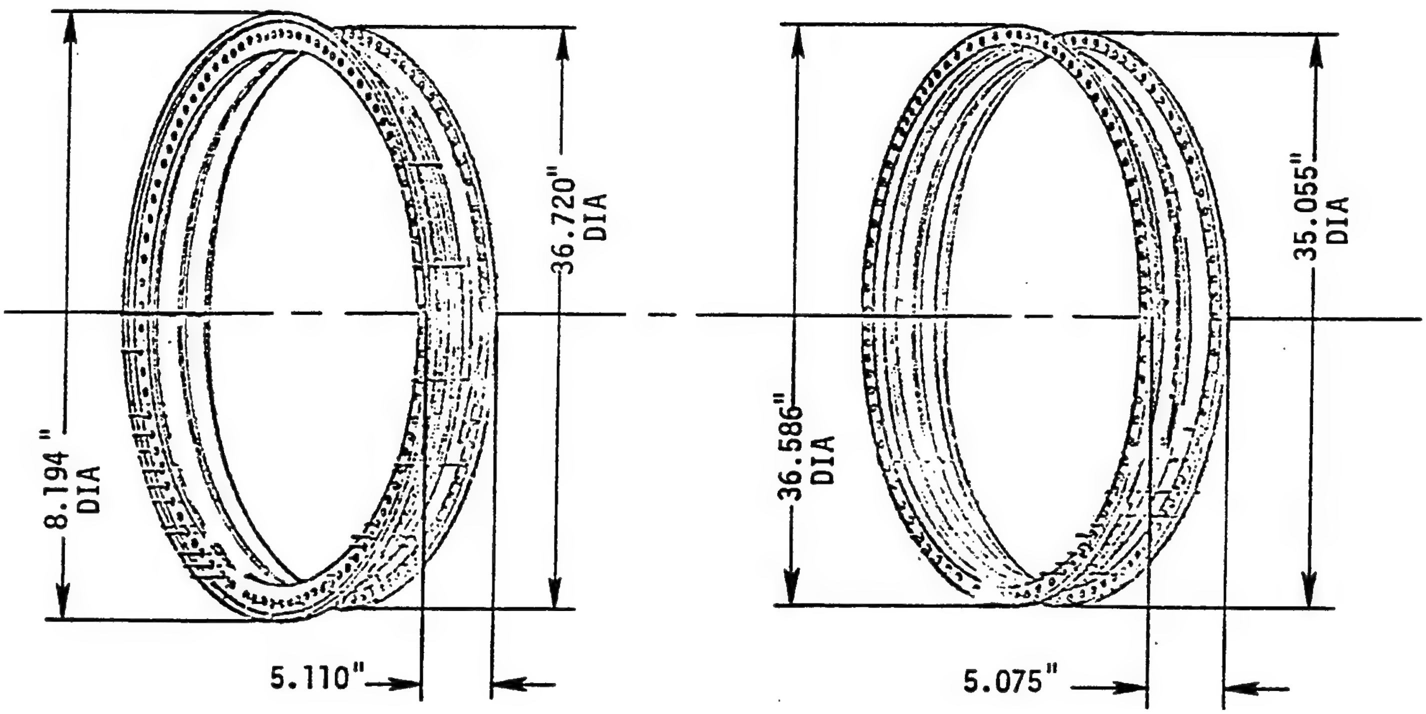


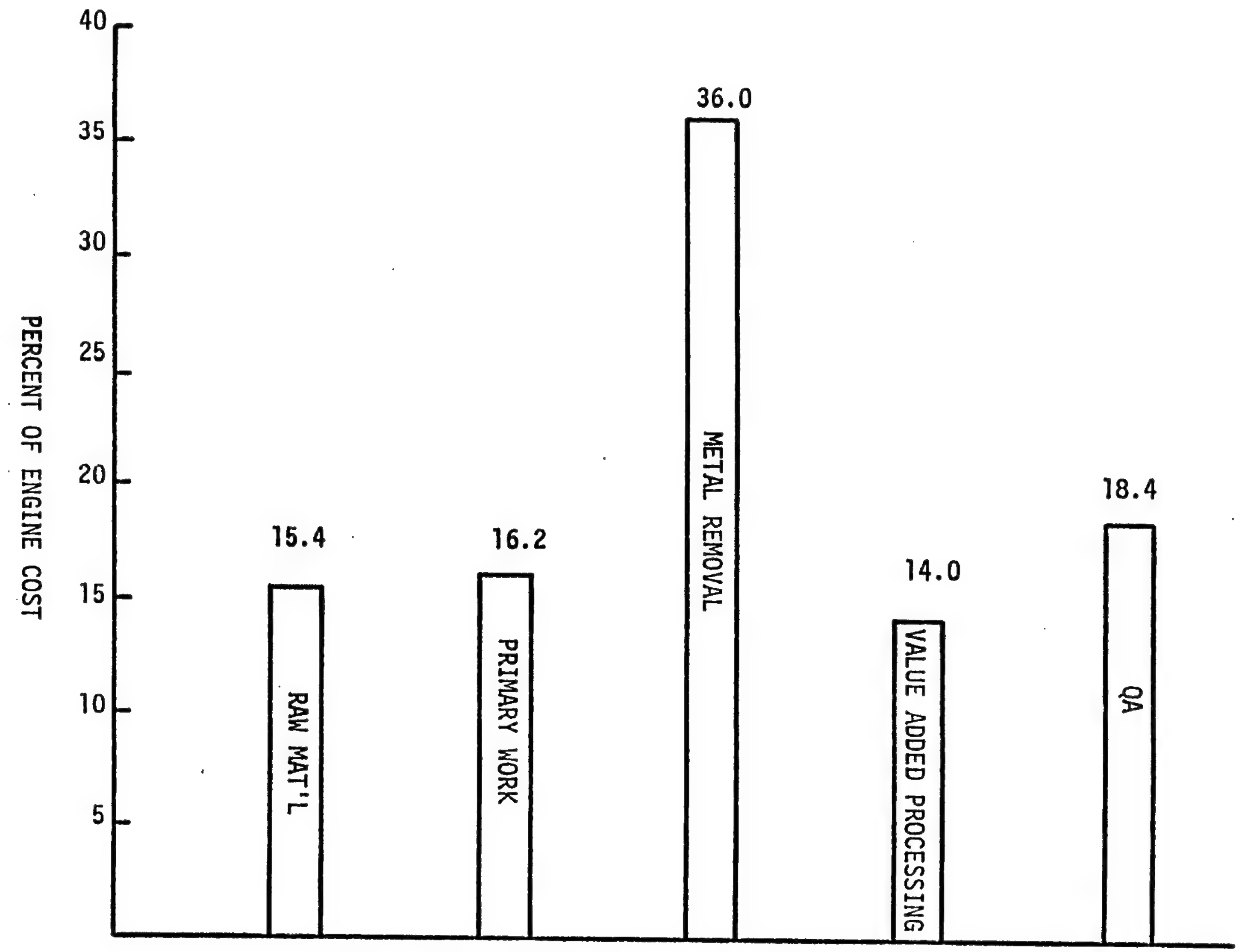
Figure D-2

TF30 P100 FAN CASE

somewhat higher (56.5%) and most of the fabrication is accomplished by metal removal utilizing turning, drilling and reaming. This part is considered "different" enough in complexity, characteristics, and fabrication techniques that it can be regarded as typical when related to compressor case construction. However, it is very similar to many other static parts.

To provide a typical set of compressor case manufacturing cost parameters, the very close similarity of cost values for both the variable and semi-variable (or nonvariable) geometry types suggests that a simple numerical average of such values could well represent both types, and appears to be appropriate to apply to compressor case fabrication in general. These averages are shown in Table D-III, which provides typical compressor case cost-to-manufacture breakdown. The data were further analyzed by grouping into the most significant cost factors, regardless of who performed them, as shown in Figure D-3. It is readily apparent that the most significant cost factor in titanium compressors falls into the general category of Metal Removal (36%). This amount includes not only the rough machining done by the primary producer prior to shipping but the significant first machining costs incurred by the engine manufacturer. The other costs were about equivalent and varied from 14% for value added processing to 18.4% for quality assurance.

Additional cost breakdown data used in developing the information provided in Figures D-1, D-2 and D-3 is included in Appendix A.



OVERALL COST PERCENTAGES - RAW MATERIAL TO FINISHED PART

TITANIUM COMPRESSOR CASE

Figure D-3

B. Inconel 718 Cases

The three Inconel 718 alloy cases shown in Figures D-4, D-5 and D-6 were studied in detail. Figures D-4 and D-5 are fabricated diffuser cases (compressor rear frames) for the TF3[illegible] and TF30 engines and represent 2.8 and 2.4%, respectively, of the total engine cost. Figure D-6 is the TF41 turbine case which is made from a rolled ring and represents 1.1% of total engine cost.

The data used in developing the cost breakdown on the three cases are provided in Appendix B. A summary of the cost by work area at the engine producer's plant is shown in Table D-IV. The TF41 turbine case is produced from a large rolled ring and contains milled vane retaining slots and has understandably high total machining cost (34.2%). The high ratio of machining performed on this case is analogous to several other static and dynamic parts such as seal rings, spacers and disks. Drilling and tapping costs are relatively high for the diffuser cases selected, due in part to necessary external equipment requirements and to provide for the attachment of adjacent assemblies. The bench work and welding on the diffusion case assemblies is typical of fabricated assemblies requiring extensive deburring and bench fit up. The higher inspection cost (9.1%) of the TF41 case is not fully explainable, however, the degree of inspection performed on this part is more akin to rotating parts than static structures in that extensive ultrasonic inspection is also required.

A detailed study of the materials cost for the TF30 diffuser case was conducted as being typical of a fabricated superalloy case. A breakdown of these costs are shown in Table D-V. It should be noted that in

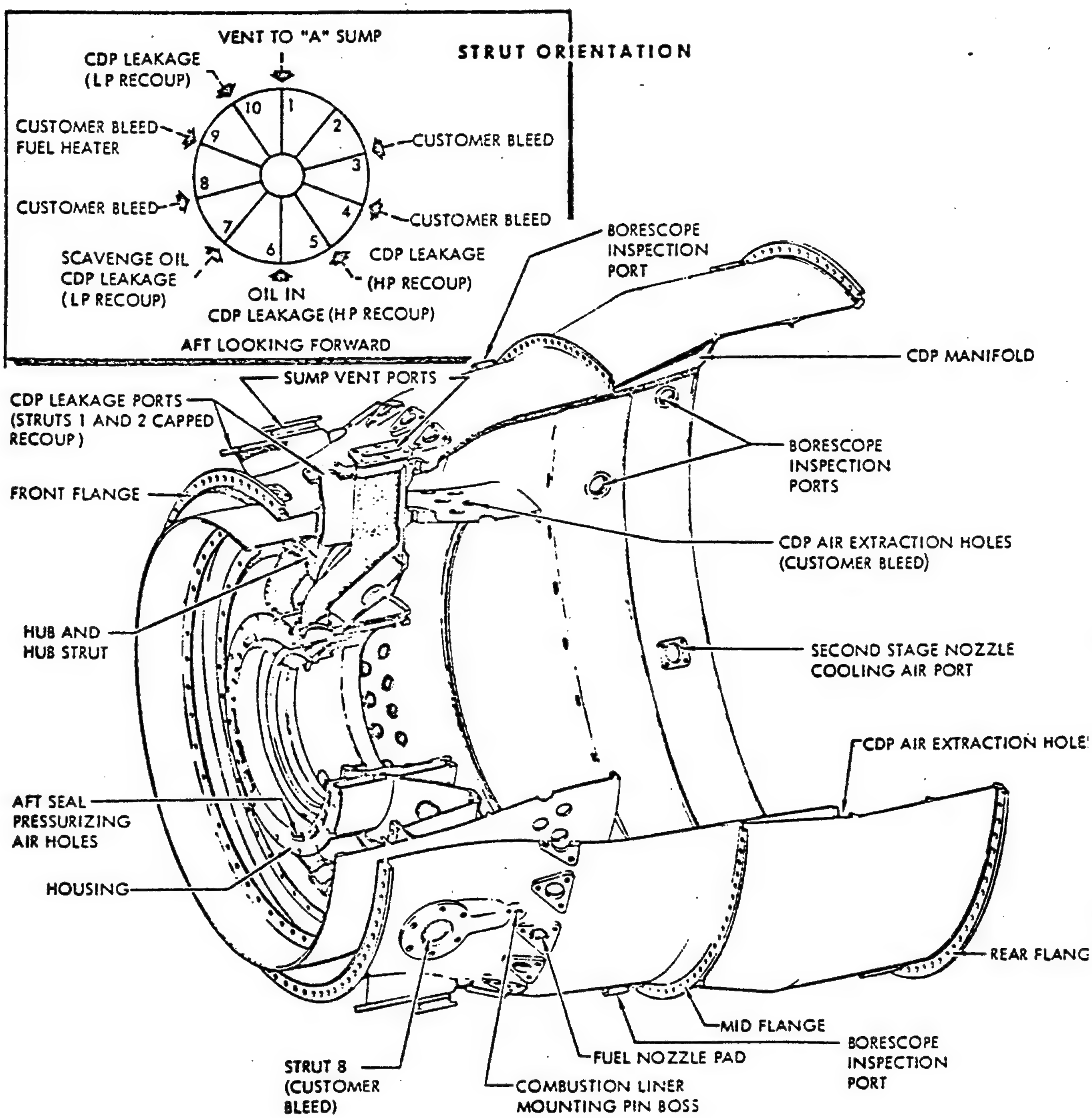


Figure D-4

TF39 COMPRESSOR REAR FRAME
(AFT Diameter ~36")

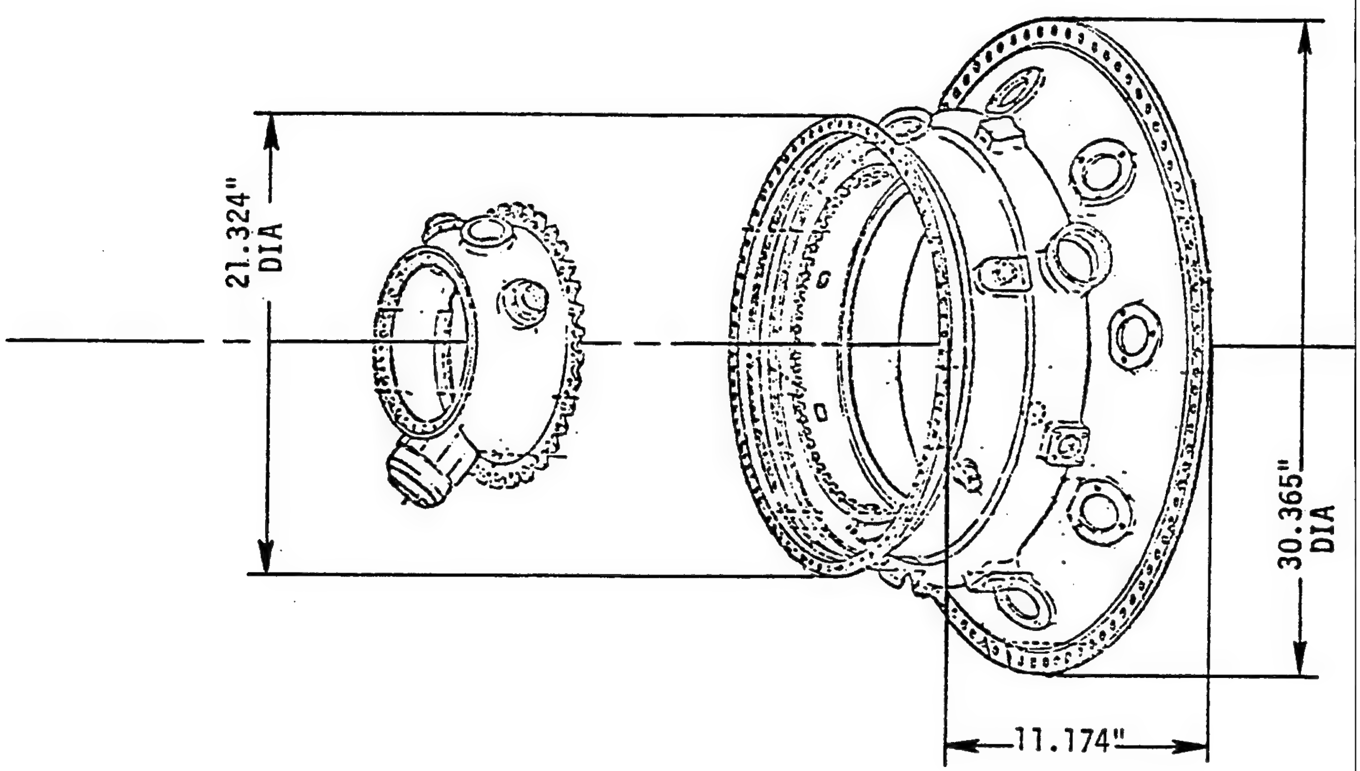
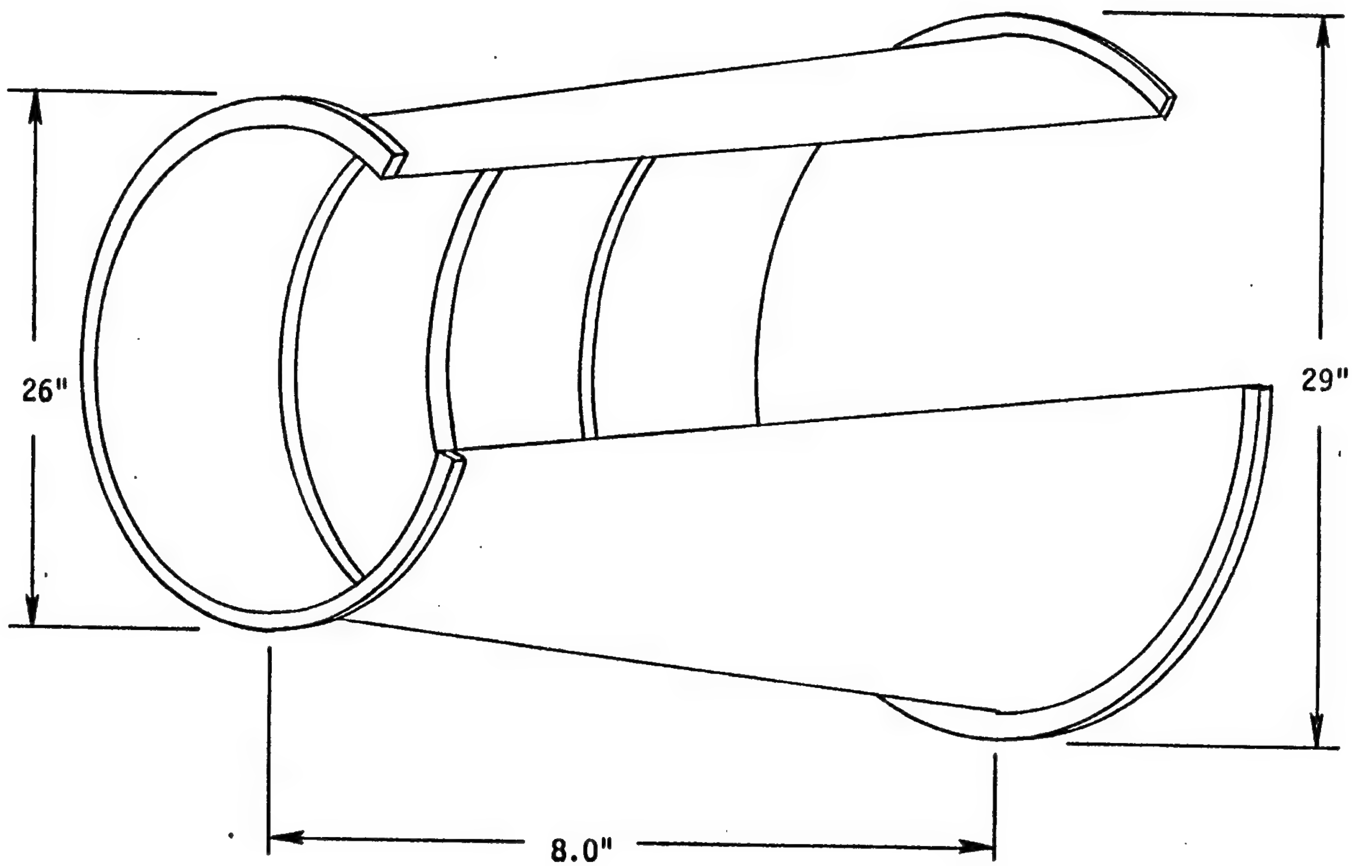


Figure D-5

TF30 DIFFUSER CASE



TF41 Tubing Case

TABLE D-IV

PERCENT OF TOTAL COST ADDED BY ENGINE MANUFACTURER

(1) PART	% OF COST	MAT'L COST	(2) LABOR COST	DRILL & TAP	MILL'G & TURN'G	WELD	BENCH	INSP'N	CLEAN	HEAT TREAT	VALUE ADDED PROCCESS'G
TF41 Turbine Case	1.1	47.0	53.0	5.4	34.2	1.9	1.9	9.1	-	-	0.5
TF30 Diffuser Case	2.5	60.6	39.4	8.8	13.7	6.1	4.2	2.9	1.3	0.4	2.1
TF39 Compr. RR Frame	2.8	57.5	42.5	3.6	16.0	11.5	4.1	3.0	0.1	0.3	3.8

(1) All Assemblies Primarily Inco 718

(2) At Power Plant Manufacturer's Plant

TABLE D-IV.a

PERCENT OF TOTAL COST ADDED BY ENGINE MANUFACTURER

PART	COST OF COMPONENT	PERCENT OF ENGINE COST	MATERIAL COST	METAL REMOVAL	OTHER*
TF-41 TURBINE CASE	$5,060	1.1	47/2378	39.6/2004	13.4/678
TF-30 DIFFUSER CASE	$25,000	2.5	60.6/15180	22.5/5625	17/4250
TF-39 COMPRESSOR RR FRAME	$19,600	2.8	57.5/11270	19.6/3841	22.8/4469

*INCLUDES - Welding, Bench, Inspection, Cleaning, Heat Treat, Value Added Processing

FOR OFFICIAL USE ONLY

TABLE D-V

TF30 DIFFUSER CASE

MATERIAL COST BREAKDOWN
(60.6% of Total Cost)

Inner & Outer Case Forgings	21.3%
Sheet Metal Components (8 Struts - 4 Manifold Segments)	10.5%
Cast Bosses (10)	9.2%
Miscellaneous Details (33) (Shields - Bushings - Sleeves - etc.	19.6%
TOTAL	60.6%

TABLE D-V.a

TF30 DIFFUSER CASE

MATERIAL COST BREAKDOWN

(60.6% of Total Cost)

Inner and Outer Case Forgings	21.3% ($5,325)
Sheet Metal Components (8 Struts-4 Manifold Segments)	10.5% ($2,625)
Cast Bosses (10)	9.2% ($2,300)
Miscellaneous Details (33) (Shields, Bushings, Sleeves, etc.)	19.6% ($4,900)
TOTAL	60.6% ($15,150)

the case selected, the inner case and the struts are fabricated from a forging and sheet metal respectively, whereas in the TF39 case these components are cast. Miscellaneous details (33 total) in the selected case amount to 19.6% of total cost. Since these parts individually represent only a small fraction of the total cost, they were not broken down into their per-part cost. Cost reductions in this area could best be approached through incorporation of these details into main body castings containing the required appendages.

In Table D-VI the major component cost (those other than the 33 miscellaneous details) are further detailed. Raw material in this breakdown is either billet, sheet, or raw castings. A further breakdown of these costs, while pertinent for other components, would represent only a minor fraction of total cost and do not appear to be lucrative areas for further study. It can be seen that machining is a major fraction of detail part cost as well as assembly manufacturing cost, as cited above. The low cost of inspection is at least in part attributable to freedom from basic materials problems associated with Inconel 718 in static structures.

Table D-VII and Figure D-7 summarize the selected diffuser case cost by major operation category. As would be expected from the above review, metal removal accounts for the largest fraction of diffuser case cost and represents the best area for further cost reduction as cited in the Recommendations Section of this report.

C. Combustors

Table D-VIII is a summary of four combustors from General

TABLE D-VI

TF30 DIFFUSER CASE

BREAKDOWN OF MAJOR COMPONENT COST
(41% of Total Cost)

COMPONENTS	PERCENT TOTAL COST	RAW MAT'L	COST BREAKDOWN			
			SHAPING	WELDING	MACHINING	INSPECTION
Case Forgings	21.3	3.8	7.5(1)	-	8.8	1.2
Sheet Metal Struts & Manifold	10.5	5.3	1.6(2)	1.1	1.5	1.0
Cast Bosses	9.2	1.3	3.5(3)	-	4.2	0.2

(1) Forging
(2) Forming
(3) Casting

TABLE D-VI.a

TF30 DIFFUSER CASE

BREAKDOWN OF MAJOR COMPONENT COST
(41% of Total Cost)

COMPONENTS	COST	RAW MAT'L	COST BREAKDOWN			
			SHAPING	WELDING	MACHINING	INSPECTION
CASE FORGINGS	% 21.3	3.8	7.5 (1)	--	8.8	1.2
	$ 5,325	950	1,875	--	2,200	300
SHEET METAL STRUTS & MANIFOLD	% 10.5	5.3	1.6 (2)	1.1	1.5	1.0
	$ 2,625	1,325	400	275	375	250
CAST BOSSES	% 9.2	1.3	3.5 (3)	--	4.2	0.2
	$ 2,300	325	875	--	1,050	50
MISC DETAILS	% 19.6					
	$ 4,900					

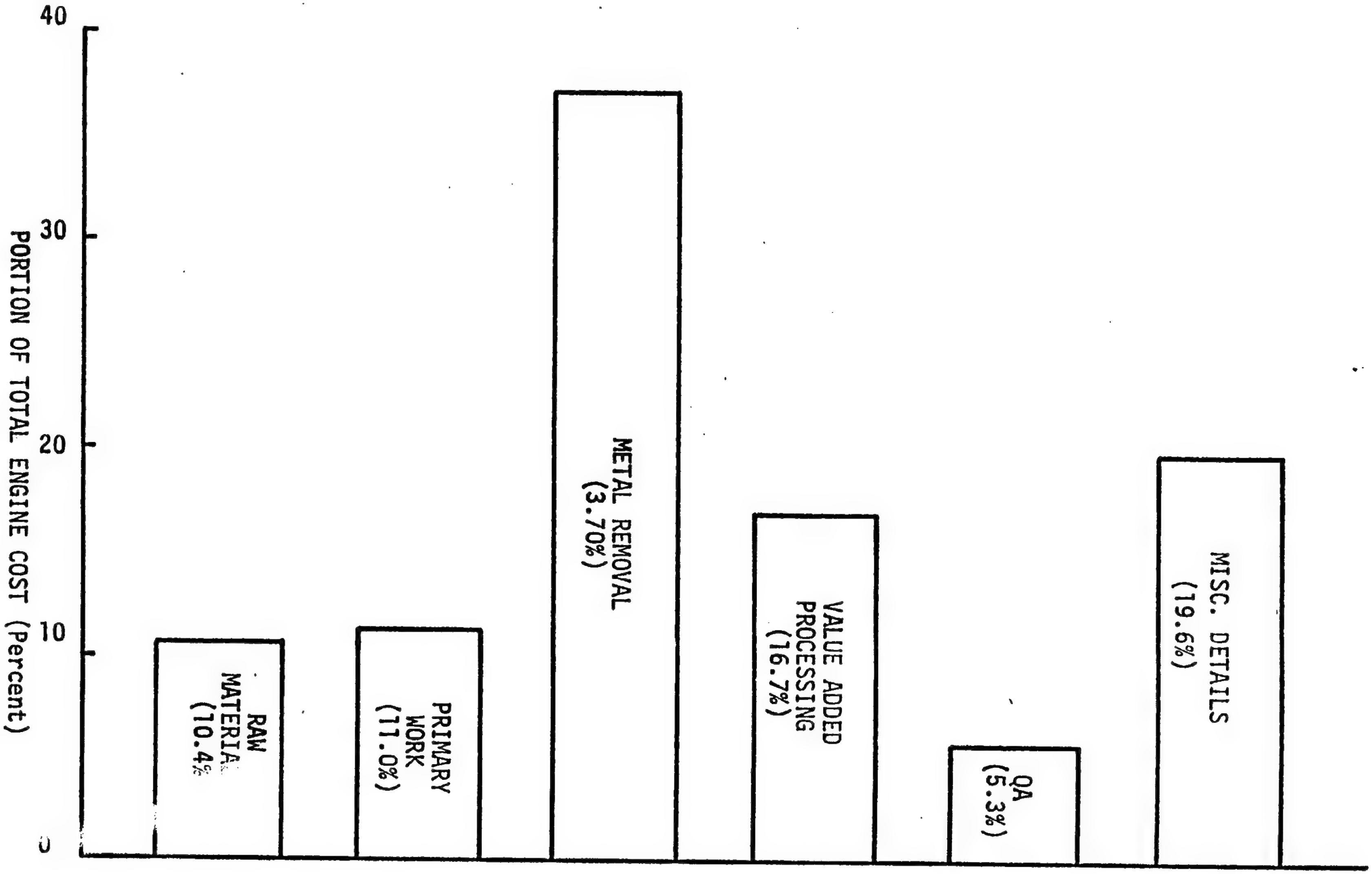
(1) Forging
(2) Forming
(3) Casting

TABLE D-VII

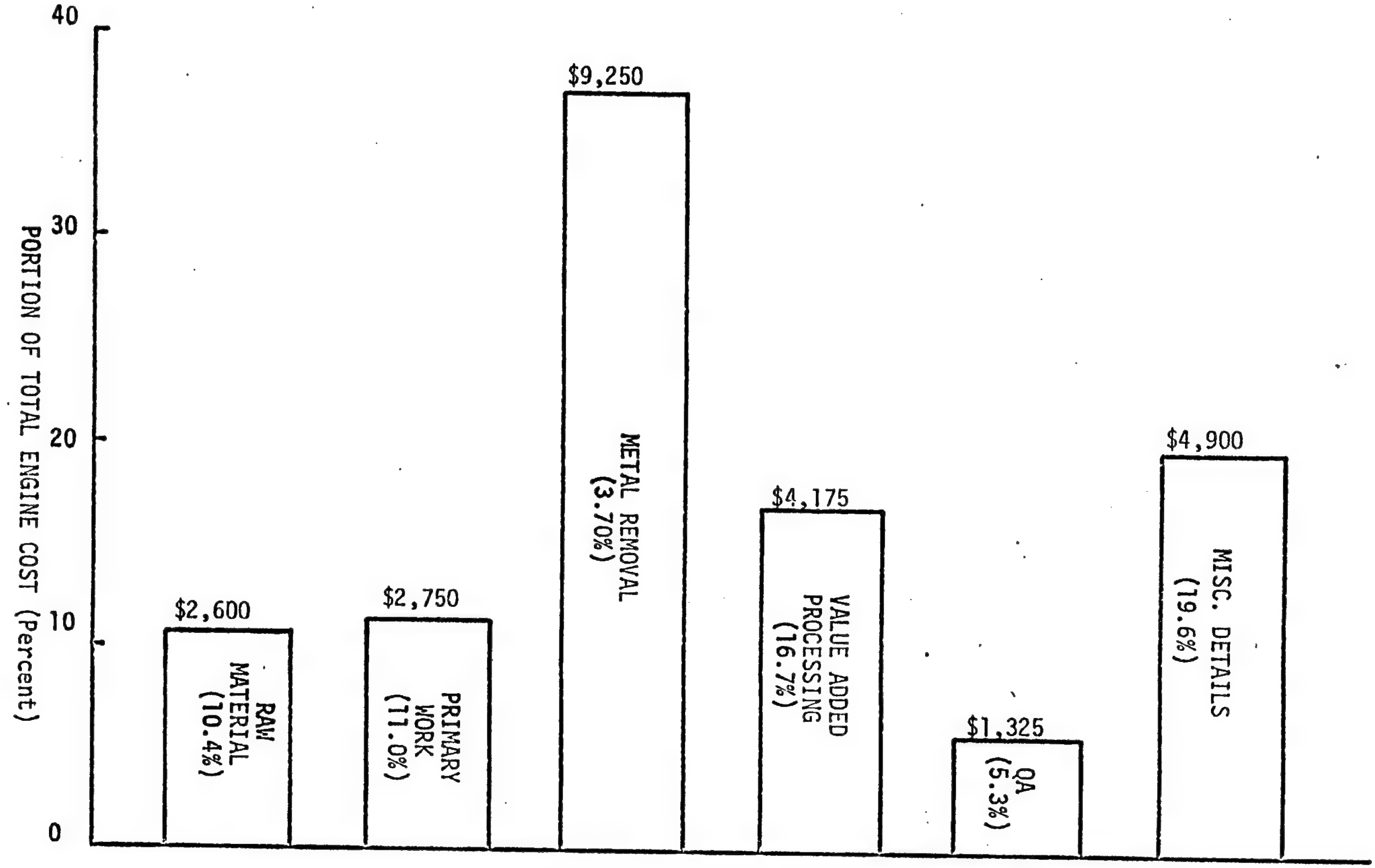
TF30 DIFFUSER CASE

COST BREAKDOWN BY OPERATIONS

Raw Material		10.4%
Primary Metal Working		11.0%
Forging	7.5%	
Casting	3.5%	
Metal Removal		37.0%
Hole Generation	8.8%	
Turning & Milling	28.2%	
Processing		16.7%
Forming	1.5%	
Welding	7.2%	
Benching	4.2%	
Cleaning	1.3%	
Heat Treat	0.4%	
Others	2.1%	
Quality Assurance		5.3%
Miscellaneous Components		19.6%
	TOTAL	100.0%



TF-30 DIFFUSER CASE MAJOR COST BREAKDOWN
Figure D-7



TF-30 DIFFUSER CASE MAJOR COST BREAKDOWN
Figure D-7.a

FOR OFFICIAL USE ONLY

TABLE D-VIII

<u>COMPARISON OF COMBUSTOR COST</u>

	J79 STD 10 CANS	TF30 8 CANS	F101 ANNULAR	J79 LOW SMOKE 10 CANS	TF39 ANNULAR	T63 1 CAN
% OF ENGINE	.5	.5	1.2	4.5	1.1	.5
MATERIAL	35.0	64.8	59.3	24.8	35.2	53.0
LABOR	65.0	35.2	40.7	75.2	64.8	47.0

TABLE D-VIII.a

COMPARISON OF COMBUSTOR COST

	J79 STD 10 CANS	TF30 8 CANS	F101* ANNULAR	J70 LOW SMOKE* 10 CANS	TF39 ANNULAR
COST OF ENGINE	$350,000	$1,000,000	-	-	$700,000
COST OF COMBUSTOR $/% ENGINE	1750/.5	5000/.5	- /1.2	- /4.5	7700/1.1
MATERIAL	$612/35%	$3240/64.8%	- /59.3%	- /24.8%	$4080/53%
LABOR	$1138/6.5%	$1760/35.2%	- /40.7%	- /75.2%	$3620/47%

*NOT STUDIED IN DETAIL

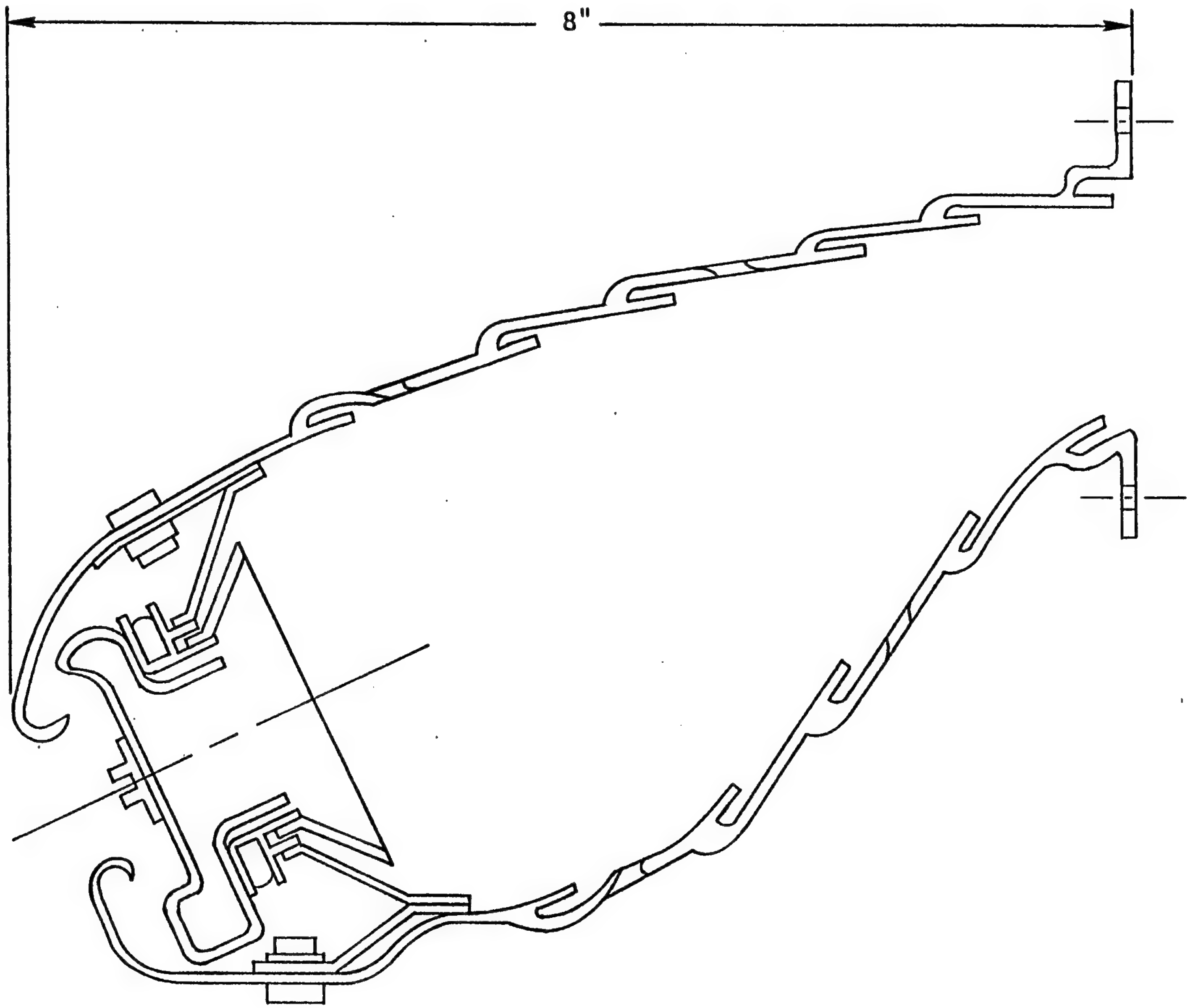
Electric, one from Pratt and Whitney and one from Allison. Except for the J79 Low Smoke and the F101 which are development combustors, all of the combustors are production hardware. The percent of engine cost of the J79 Low Smoke and F101 combustor are higher than others because they are development parts. The configuration of three types of combustors are shown in Figures D-8 through D-10.

The F101 is considered a Machined Combustor since its major components, the outer liner and inner liner, are turned from a rolled and welded ring. The J79 Low Smoke utilizes a forged inner liner. Except for a few L605 cast and wear rings, the remainder of all combustors are essentially sheet Hastelloy X.

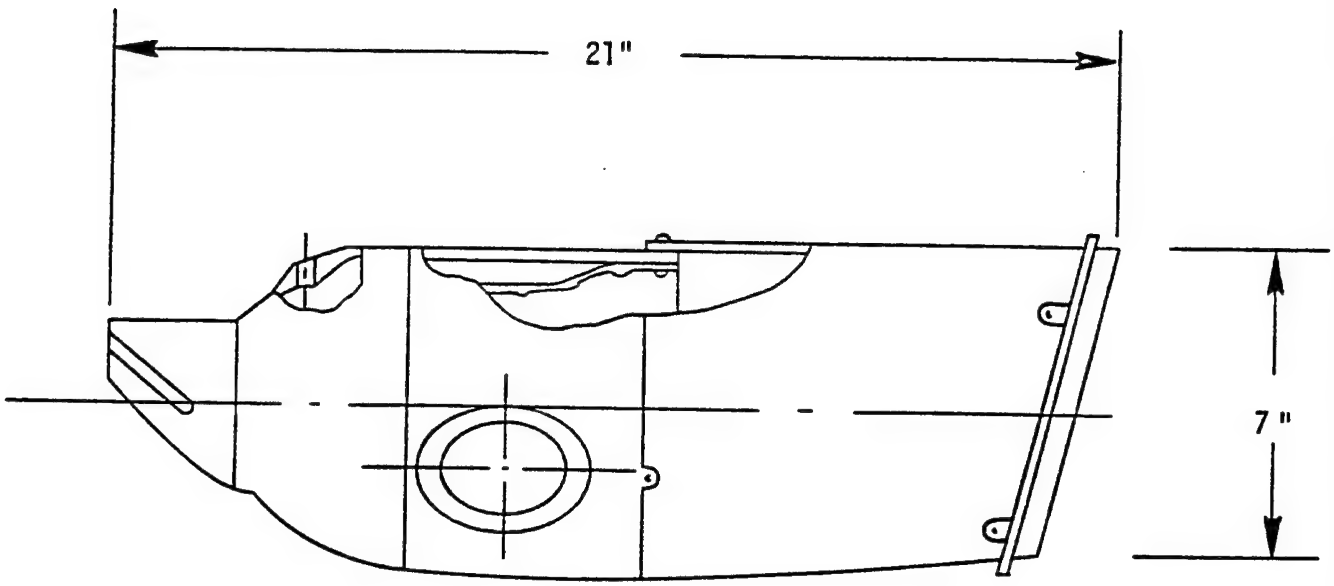
"Material" as listed, represents all outside vendor purchased parts and services. "Labor" represents all in-house standard labor with factors which include set up, rework and applicable overhead.

Table D-IX has been broken into 8 major categories in order to more easily identify those areas of effort which could result in meaningful cost savings. These data are graphically shown in Figures D-11 and D-12. J79 Std. and TF30 are of comparable size, construction, and production status and are listed side by side for direct comparison with the F101 which is in development.

- Raw material includes all material input only.
- Primary work includes all processing such as:
  - Melting, Forging, Hot and Cold Rolling and Heat Treatment
- Hole generation includes drilling, piercing, slotting and EDM.



MACHINED COMBUSTOR
Figure D-8



Fabricated Combustor

Figure D-9

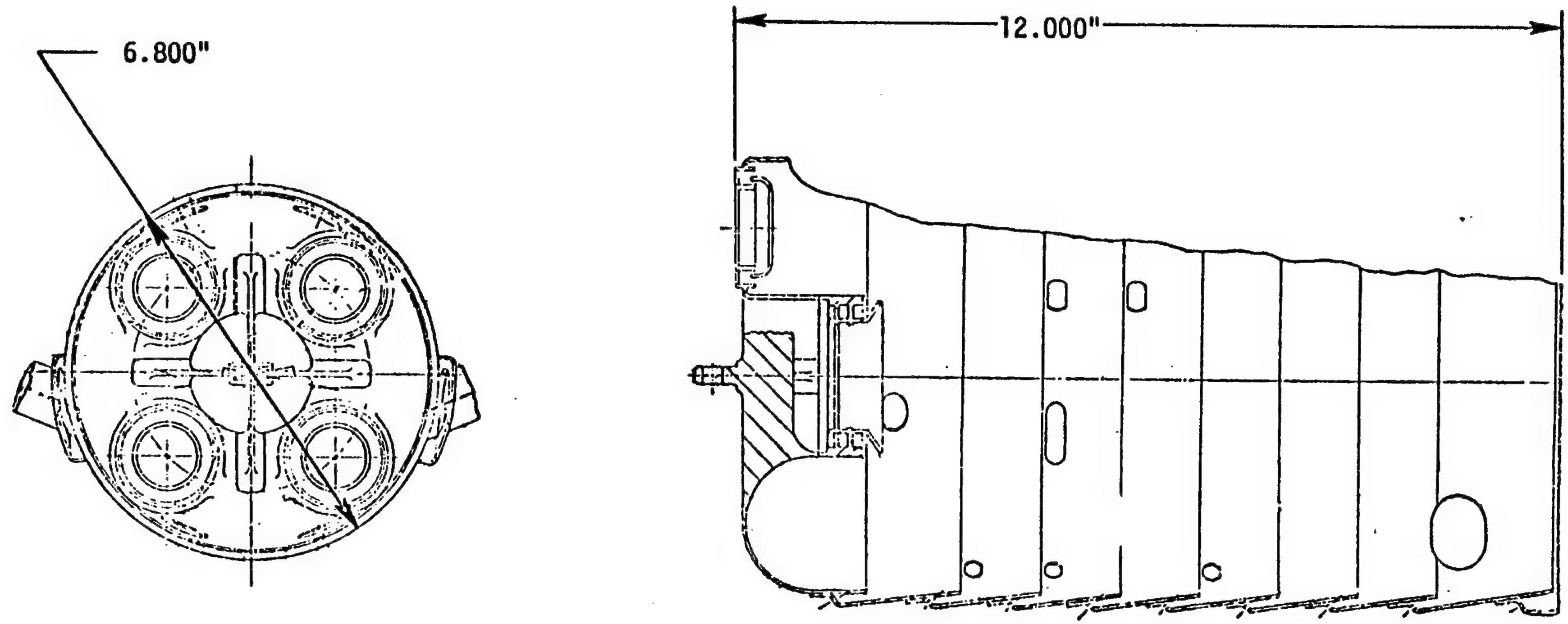


Figure D-10

COMBUSTION CHAMBER

TABLE D-IX

DISTRIBUTION OF LABOR AND MATERIAL ON COMBUSTORS

	J79 STD	TF30	F101	J79 LOW SMOKE	TF39	T63
	L&M	L&M	L&M	Labor Only	Labor Only	Labor Only
Raw Material	22.7	16.9	4.9	-	-	-
Primary Work	10.5	7.8	2.2	-	-	-
Hole Generation	14.1	14.0	14.3	17.4	6.9	7.9
Joining	25.6	8.0	14.9	15.5	17.0	11.5
Metal Removal	2.9	15.8	13.3	11.3	.7	5.6
Bench & Ass'y	16.2	7.2	29.2	16.4	20.5	12.2
Others	4.5	25.1	12.2	11.3	14.8	5.4
Q.A.	3.5	5.1	9.0	3.3	4.9	4.4

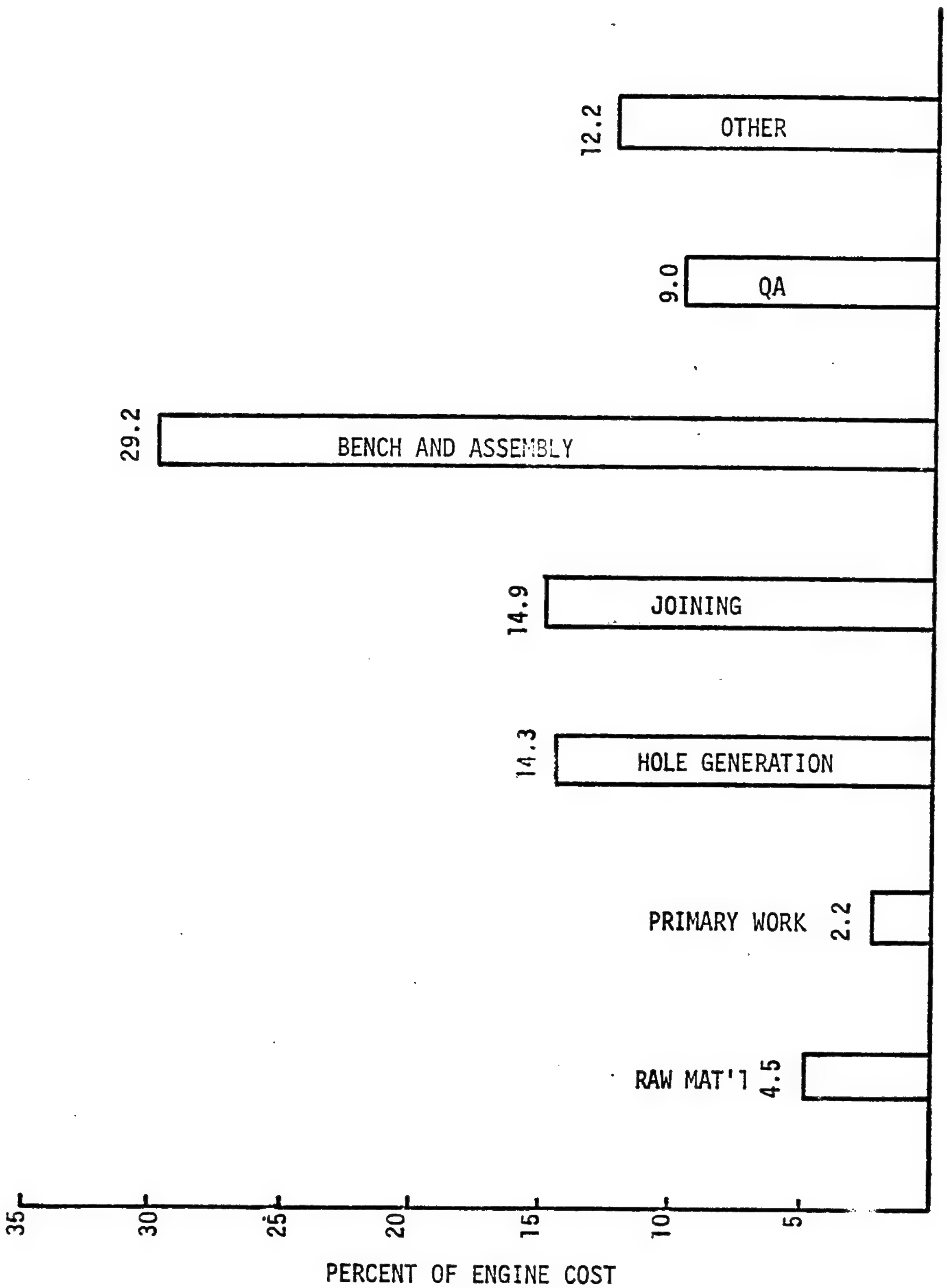
TABLE D-IX.a

DISTRIBUTION OF LABOR AND MATERIAL ON COMBUSTORS

ITEM / Component Cost	J79 STD	TF30	TF39*
	.5%/$1,750	.5%/$5,000	1.1%/$7,700
RAW MAT'L	22.7%/$397	16.9%/$845	--
PRIMARY WORK	10.5%/$184	7.8%/$390	--
HOLE GENERATION	14.1%/$247	14.0%/$700	6.9%/$531
JOINING	25.6%/$448	8.9%/$400	17.0%/$1309
METAL REMOVAL	2.9%/$50	15.8%/$790	0.7%/$54
BENCH & ASS'Y	16.2%/$283	7.2%/$350	20.5%/$1579
Q.A.	3.5%/$61	5.1%/$255	4.9%/$377
OTHERS	4.5%/$79	25.1%/$1,255	14.8%/$1,140

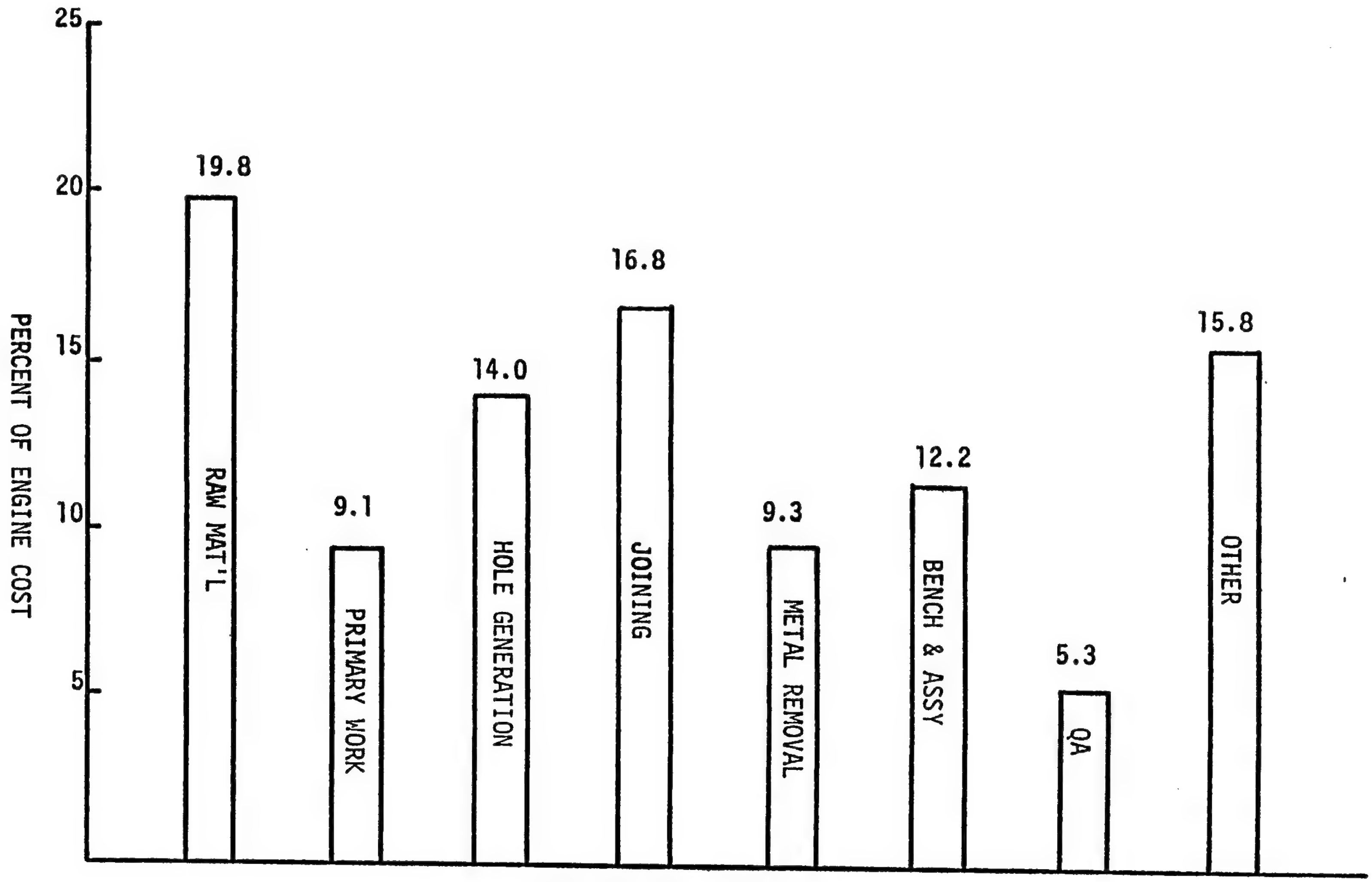
*LABOR ONLY

FOR OFFICIAL USE ONLY



F101 COMBUSTOR CAN

Figure D-11



TF30/J79 COMBUSTOR CANS

Figure D-12

- Joining includes brazing, EBW, TIG, resistance weld, riveting and bolting.
- Metal removal includes milling, broaching, turning and ECM
- Bench and assembly includes deburring, breaking sharp edges, fit ups and trim.
- Others include mainly press work such as rolling, shearing, blanking, forming, and crimping. The remainders are coating, heat treat and clean.
- Q.A. includes both dimensional/visual inspection, as well as nondestructive inspection such as fluorescent penetrant and x-ray.

It is interesting to note that the F101 material cost percentage is low due to the high work content generally required when a design freeze has not occurred. When the design is frozen, the material percentage will increase while there will be an accompanying decrease in bench and assembly, others and Q.A.

VI. APPENDIX D-1 TITANIUM COMPRESSOR CASE SUPPORTING INFORMATION

Operations

1. Flange Cylinder Forging

   Receiving Inspection

2. Machine outside diameters of Cylinder and Flange Faces - leave .040 stock on surfaces adjacent to hole areas.

3. Split into halves.

4. Machine Splitlines each half and prepare for EB weld joint.

5. EB weld on L shaped Splitline Flanges.

   Add Filler weld where necessary.

6. Rough Machine Splitlines of rails - drill and ream for (4) process construction dowels.

7. Using dowels, assemble the two halves.

8. Tack weld halves together at edges of Splitline Flanges using fabricated temporary titanium strips - this is a process weld and no x-ray necessary.

9. Assemble manifold onto case and weld in dry box - and pressure test.

10. Clean for heat treat.

    Anneal per drawing - be sure and use four rounding rings - one at each end and two under manifold ribs.

    Fluorescent inspection.

11. Cutoff tack weld strips and finish machine spline faces - finish machine the side contour of Splitline Flanges.

12. Drill, ream and tap all holes on Splitline Flanges.

13. Use four dowels on Splitline Flanges.

    Assemble and bolt the two halves together.

14. Finish machine end face and rough bore ID for the preparation of Metco 601 (EPS 10460).

15. Reverse and do opposite end same as Oper. 14.

16. Spray coat ID per EPS 10460 (Metco 601).

17. Finish Machine ID complete.

    a. Rough machine Metco 601

    b. Finish machine all grooves

    c. Finish machine Metco 601

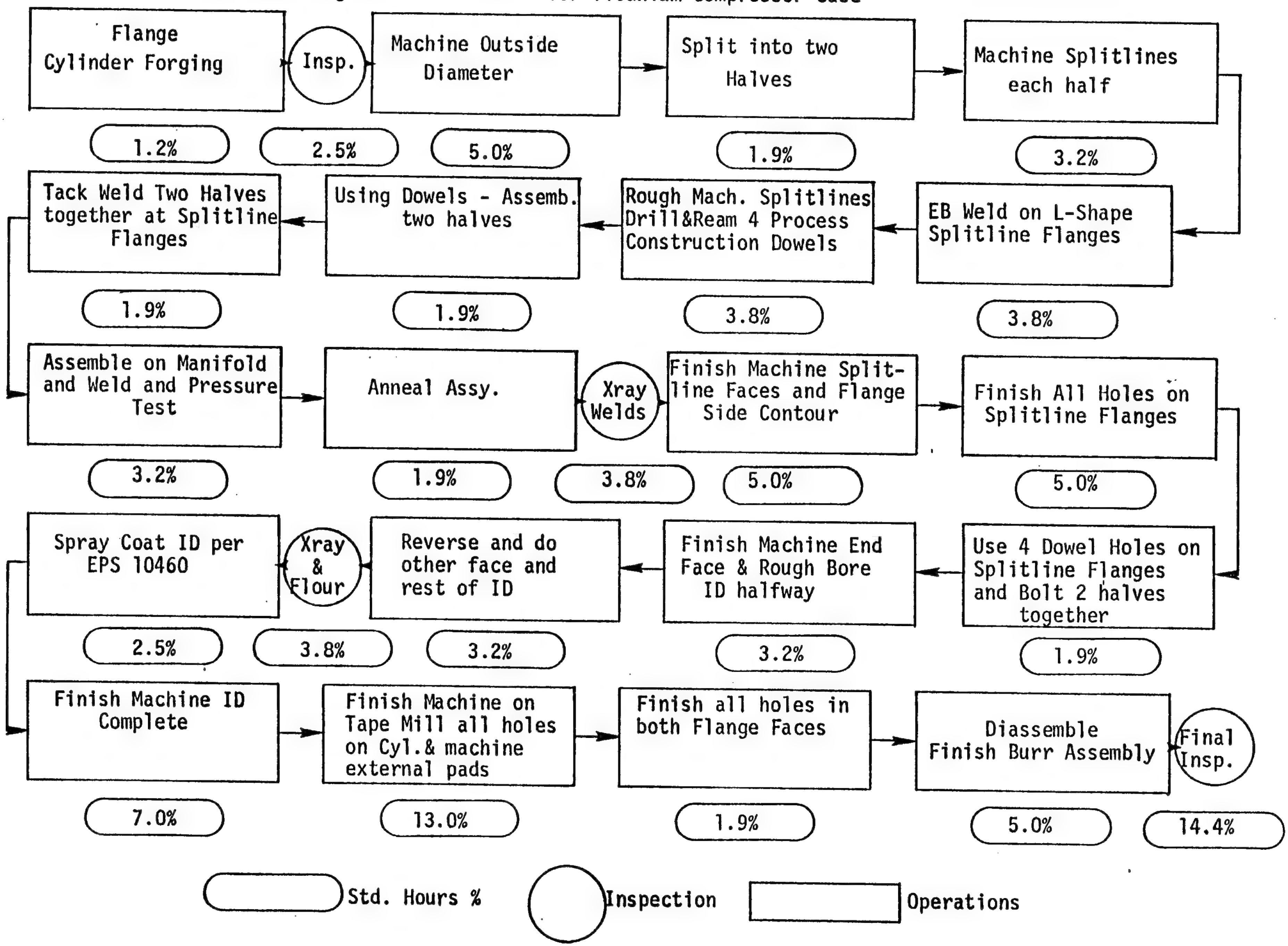
18. Finish machine on Tape Mill all holes on Cylinder and external pads, etc.

19. Finish all holes in both flange faces.

20. Disassemble and finish burr assembly.

Figure D-13

Manufacturing Model Flow Chart for Titanium Compressor Case



TITANIUM COMPRESSOR CASE

AMS 4928

Ti 6Al 4V

1. Handling

   Qualify; sample check and special lab test

2. Turn and bore - vertical-bullard
3. Mill - horizontal (narrow cutter)
4. Horizontal - mill
5. EB weld - butt to L - shape rail (Hamilton-Standard)
6. Mill - horizontal - drill on press
7. -
8. Inert gas shield arc tack (hand)
9. -
10. Mineral spirits wash

    1400°F - 2Hr - vacuum - back bas fill and fan cool

    X-ray and FPI

11. Mill
12. Drill and ream
13. -
14. Bullard - vertical
15. Bullard - vertical
16. Special designed machine
17. Bullard - vertical
18. Milwaukee - matic
19. Drill and ream

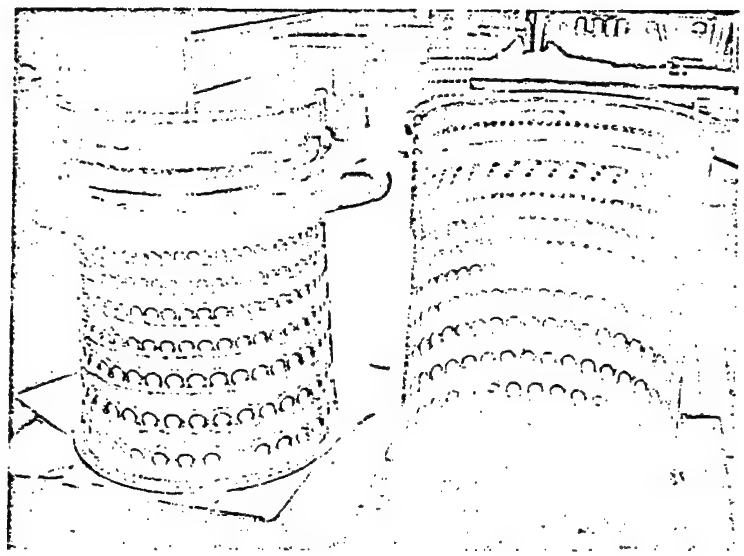


Figure D-14

TITANIUM COMPRESSOR CASE

Figure D-15

MFG CYCLE - FLOW CHART

Front Compressor Casing Machining CF6

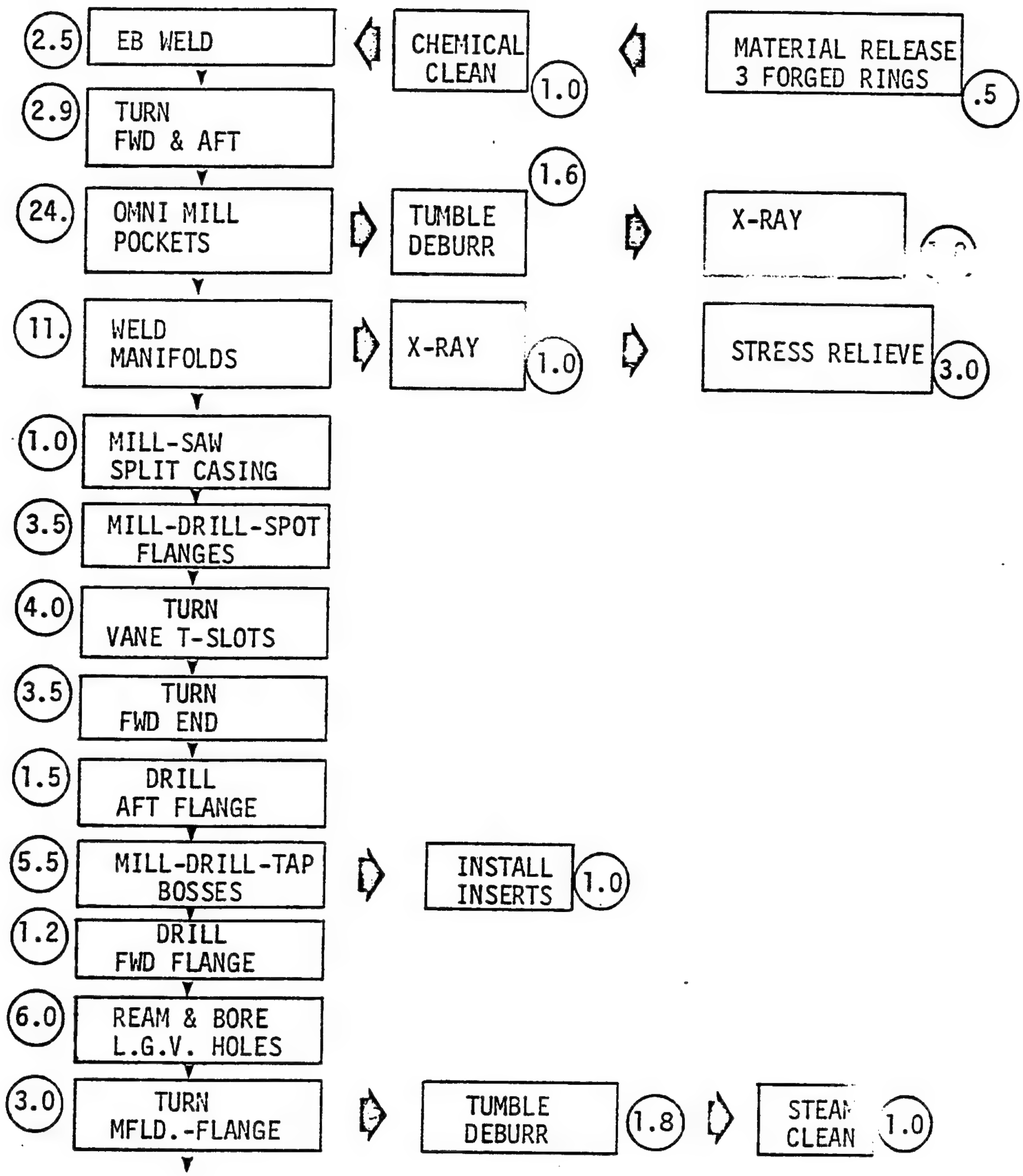
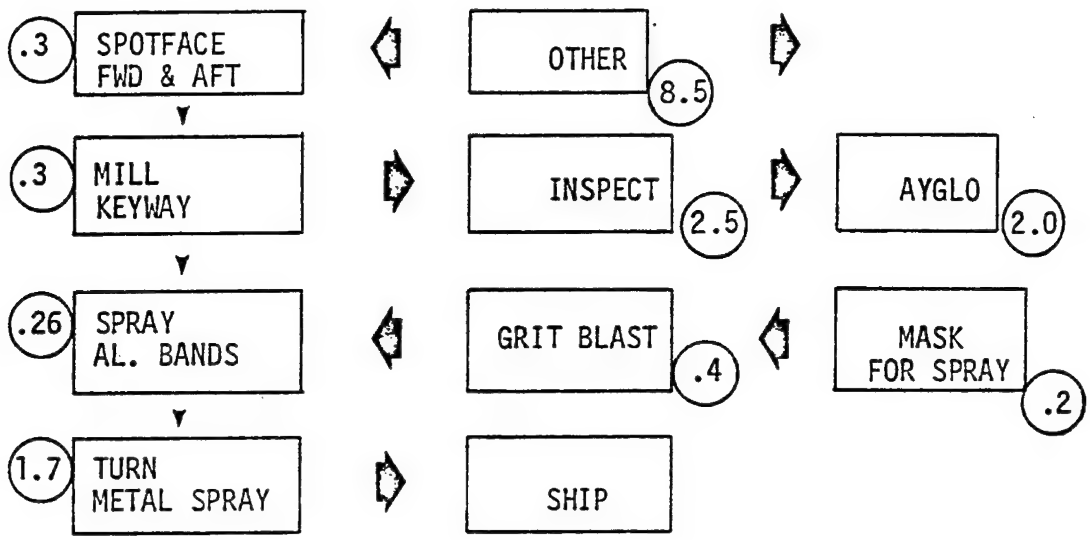


Figure D-15 (Con't)



Procured Material

Three (3) 6-4 titanium Ring Forgings
Two (2) 5-2.5 Ti Sheet Mflds.

______________ 49.0%

Labor and Overhead ______________ 51.0%

(X) Marked in circles indicate percentage of total in-house manufacturing cost

OTHER (8.5) Takes into account service charges for a) set ups, b) visual inspection, c) cleaning, d) in-process inspections, and e) misc.

WEIGHTS	AS FORGED	AS PREPPED FOR WELD
Fwd Ring	120 lbs	65 lbs
Mid Ring	620 lbs	347 lbs
Aft Ring	420 lbs	268 lbs
Manifolds	-	10 lbs
	1160	700
Finish Machined	140.2 lbs	

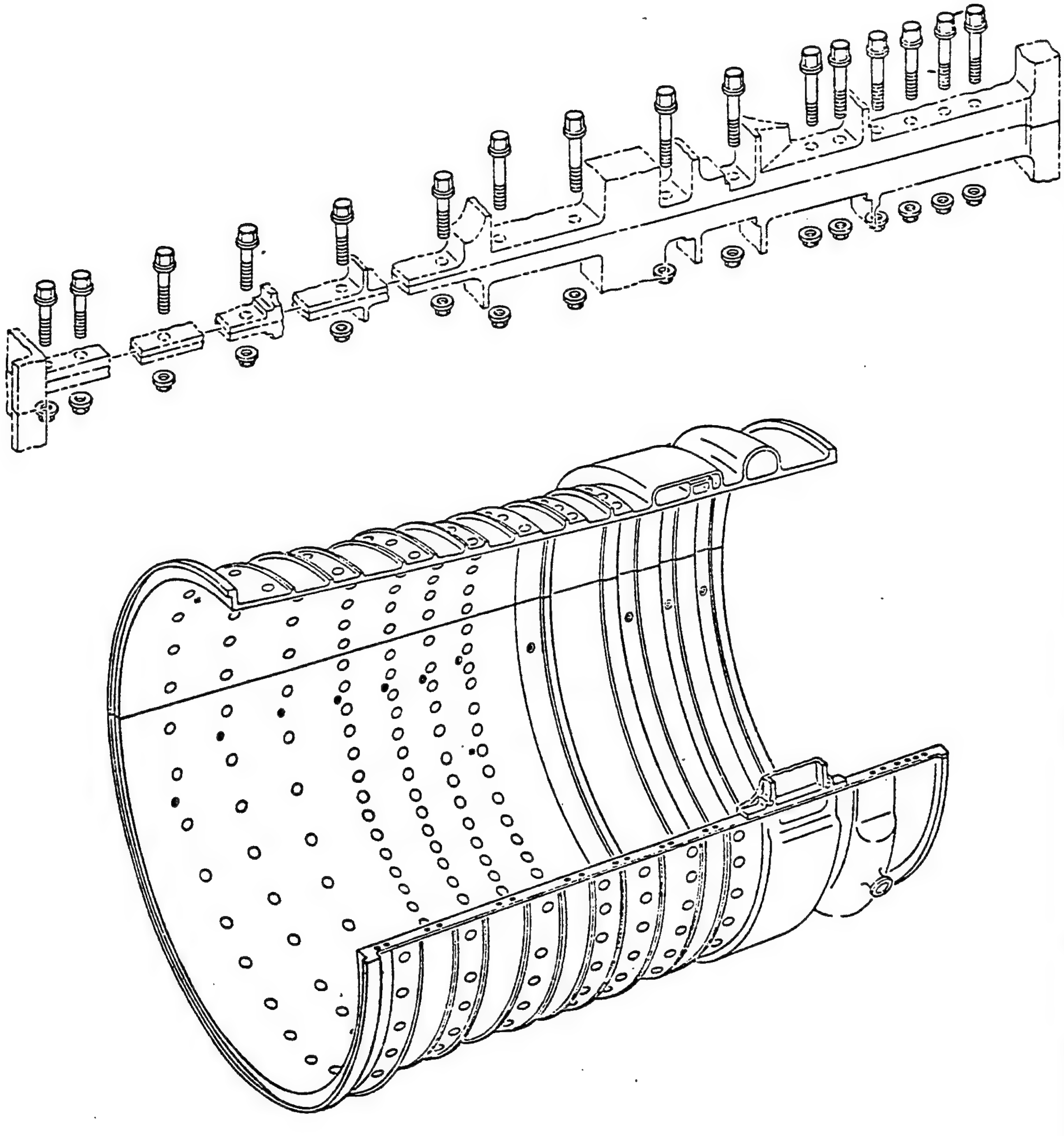


Figure D-16

TITANIUM COMPRESSOR CASE
(CF-6)

TABLE D-X

PERCENT OF COST BY MAJOR PROCESSES

TYPE OF OPERATION	% OF MFG. COST	% TOTAL PART COST
1. Welding		
Tack Weld Rings - TIG	.6	.36
EB Welding	1.5	.76
Tack Weld MFLD's - TIG	3.4	1.74
TIG Weld MFLD's	3.1	1.58
TIG Weld Target Lugs	.3	.15
	8.9%	4.54%
2. Machining		
A. Turnings		
Set up	.6	.36
Turn Aft End	2.8	1.43
Turn Fwd End	.5	.25
Set up	3.0	1.53
Target Fwd End	1.5	.76
Set up	.5	.25
Turn Aft End	2.8	1.43
Set up	.6	.36
Turn T-Slots	1.5	.76
Set up	---	----
Turn Fwd End	4.5	2.3
Set up	.6	.36
Turn Metal Spray	.6	.36
	19.5%	9.95%
B. Milling		
Set up	.3	.15
Mill Flange Pocket	2.9	1.48
Omnimil Pocket 3 & 4	4.1	2.09
Omnimil Pocket 5 & 6	4.3	2.19
Omnimil Pocket 7 & 8	2.5	1.28
Omnimil Pocket 9 & 10	1.9	.97
Omnimil Bos & Scal	1.9	.97
Omnimil Box & Bkt	3.7	1.89
Mill Ribs & Bleed Holes	1.5	.76
Set up	1.0	.51
Mill Saw-Split Case	.8	.41
Set up	1.2	.61
Mill-Drill Horiz. Flg.	1.8	.92
Set up	.5	.25
Mill Keyway	.3	.15
	28.7%	14.6%

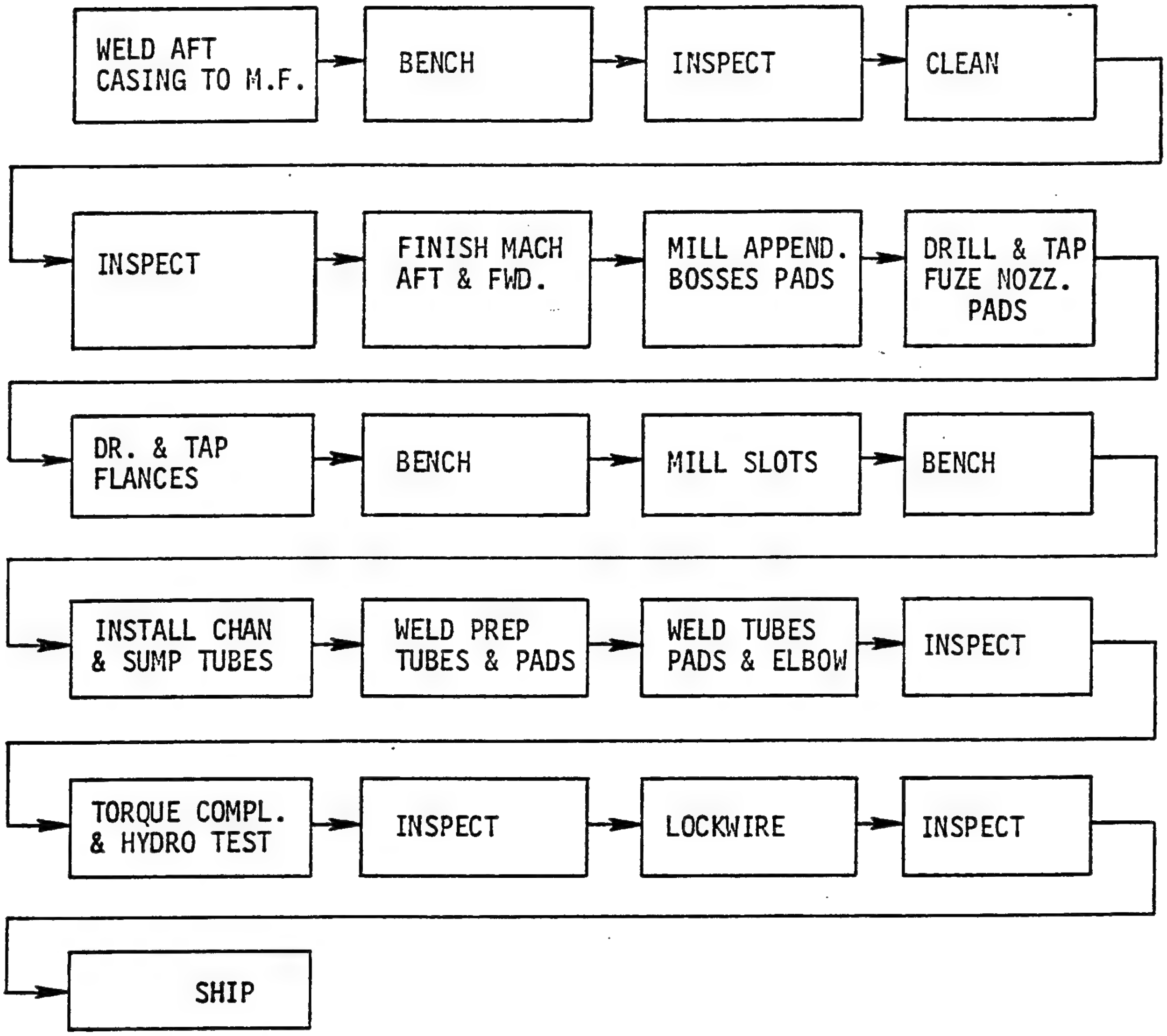
TABLE D-X (Con't)

	% OF MFG. COST	% TOTAL ART COST
C. Drilling, Tap, Ream		
Back Spot Face	.6	.3
Drill Aft Flg. Hole	1.0	.51
Mill-Drill Bosses	7.7	3.92
Set up	.1	.05
Tap Bosses	1.4	.71
Drill Fwd. Flg.	1.0	.51
Set up	1.2	.61
Ream Stg. 6 IGV	2.0	1.02
Co-Bore Stg. 6 IGV	2.6	1.32
Spot Face Fwd. & Aft.	.2	.1
	17.8%	9.08%
3. Processing		
Material Release	1.2	.61
Chem Clean	1.1	.58
Stress Relief	1.5	.76
Steam Clean	1.0	.51
Metal Spray	4.8	2.45
Grit Blast	.4	.2
	10.0%	5.1%
4. Inspection		
Inspect EB Weld	.15	.08
Inspect Mill & Burr	.6	.3
X-ray EB Weld	.3	.15
Inspect MFLD. Weld	.15	.08
X-ray MFLD. Weld	.5	.25
Visual Inspect H/T	.2	.1
Zyglo Welds	.6	.3
Dimensional Inspect	.15	.08
Inspect Csg. Lower	.7	.35
Inspect Csg. Upper	.8	.4
Zyglo	2.5	1.27
Inspect Spray	.3	.15
Inspect Prep/Ship	.3	.15
	7.6%	3.88%

TABLE D-X (Con't)

	% OF MFG. COST	% TOTAL PART COST
5. Deburring & Others		
Deburr	1.4	.71
Install Inserts	.6	.3
Deburr	1.4	.71
Other - Misc.	4.1	2.09
	7.5%	3.82%

VII. APPENDIX D-2 SUPERALLOY FRAMES SUPPORTING DATA



NOTE: Weld is mainly TIG

Figure D-17. TF39 Rear Compressor Frame
Final Assembly
Flow Chart

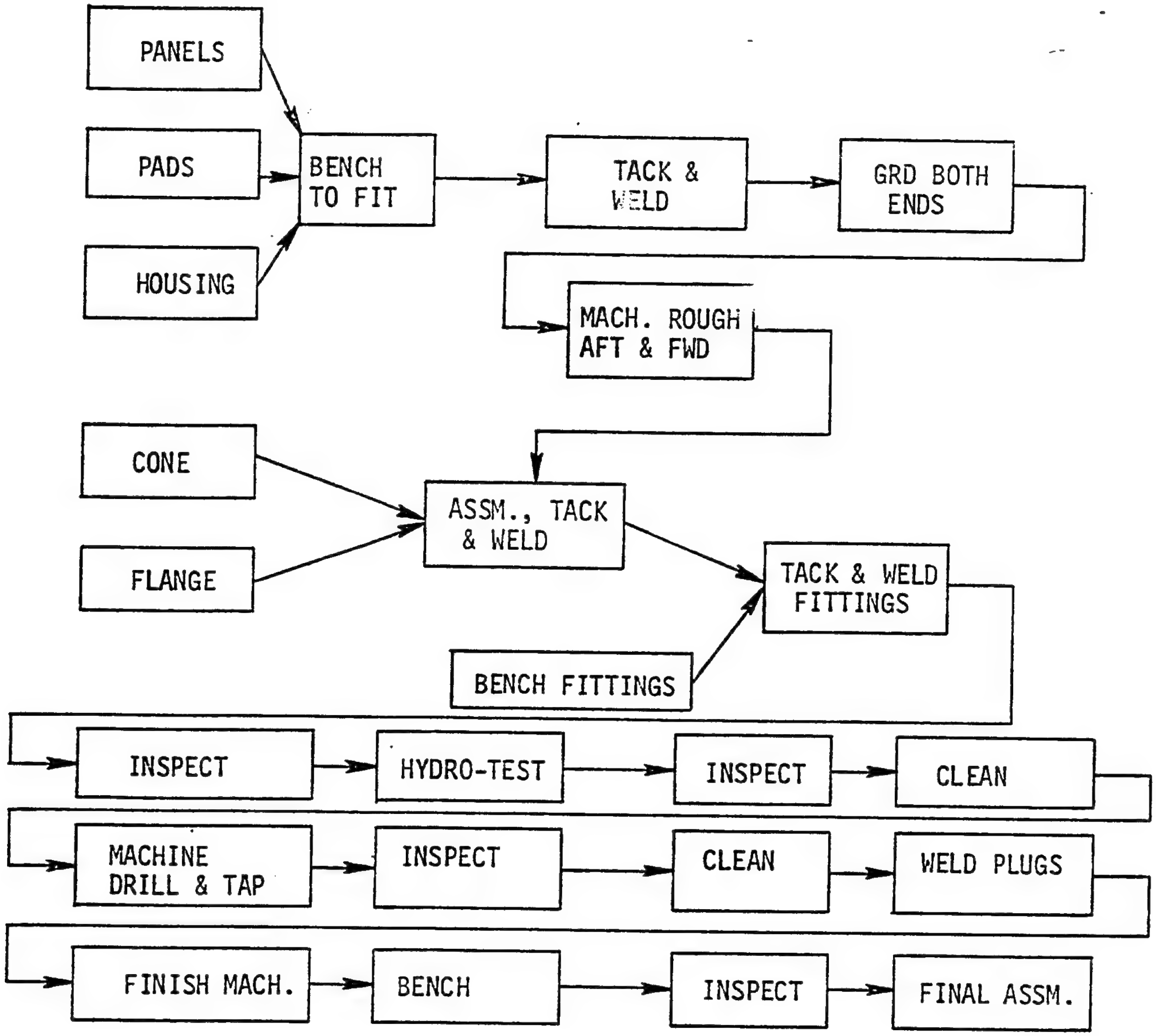


Figure D-18. TF39 Rear Compressor Frame
Sump Subassembly
Flow Chart

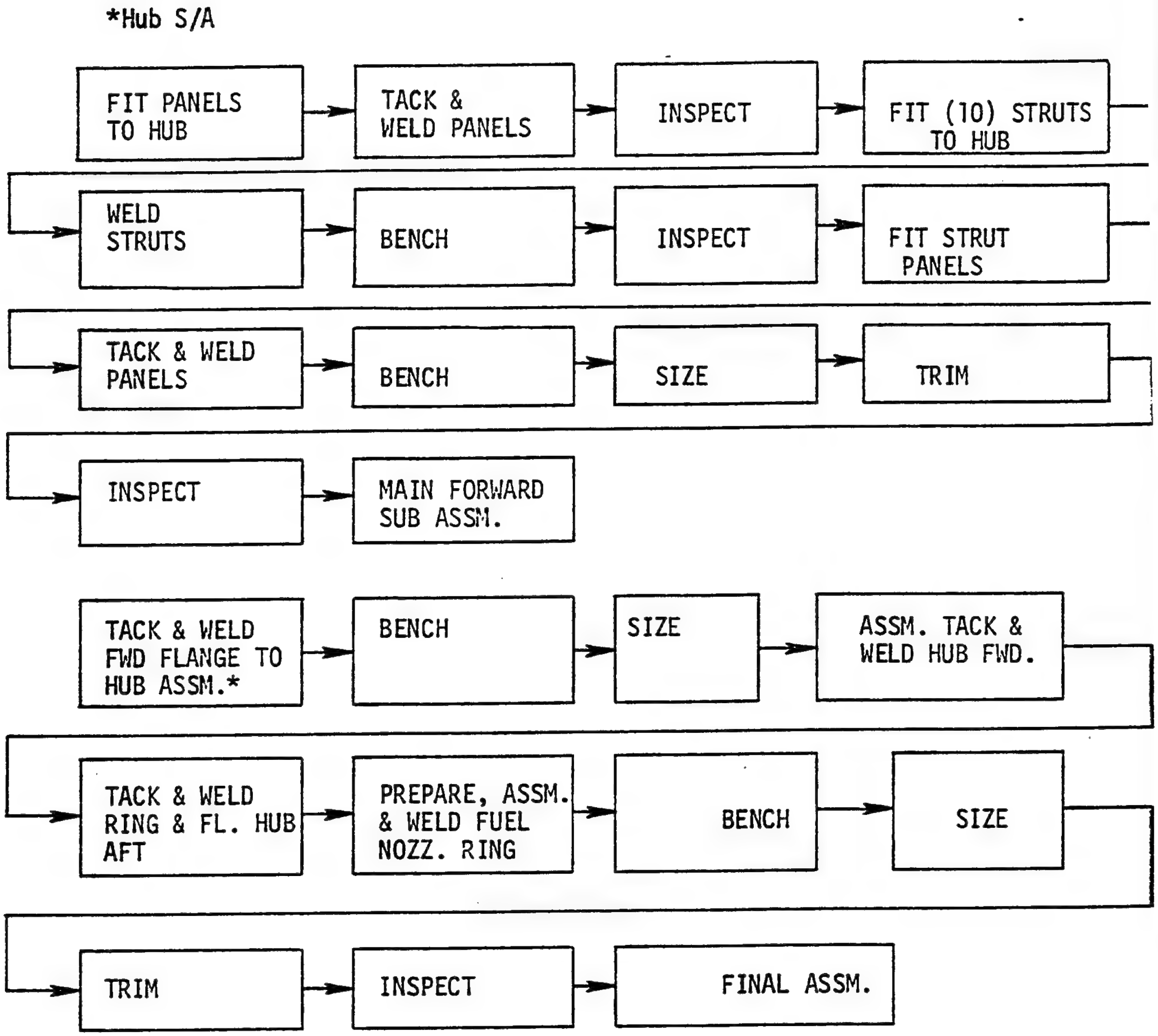


Figure D-19. TF39 Rear Compressor Frame
Main Forward Subassembly Flow Chart

Figure D-20 TF30 DIFFUSER CASE - Flow Chart

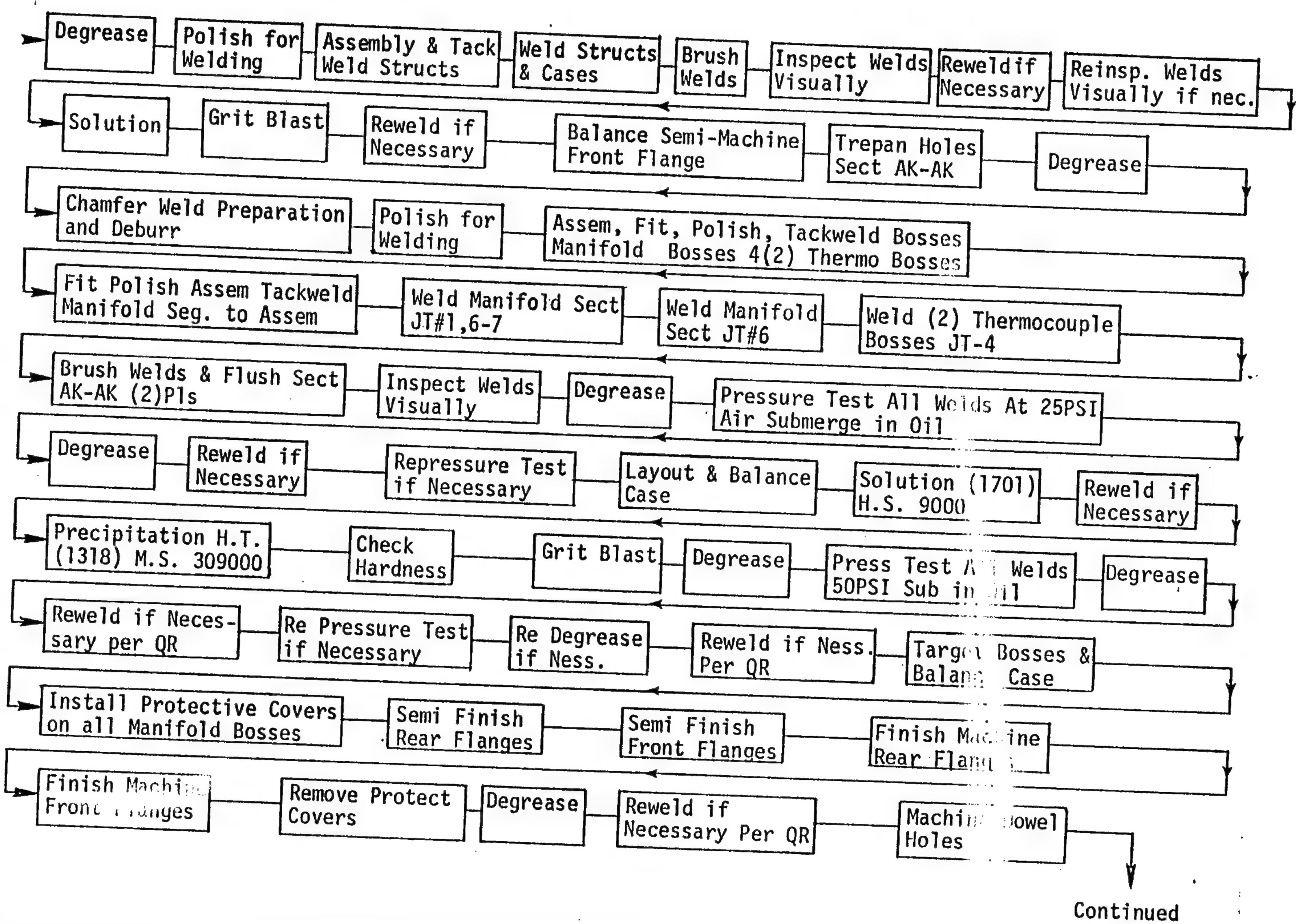


Figure D-20 TF30 DIFFUSER CASE - Flow Chart - Continued

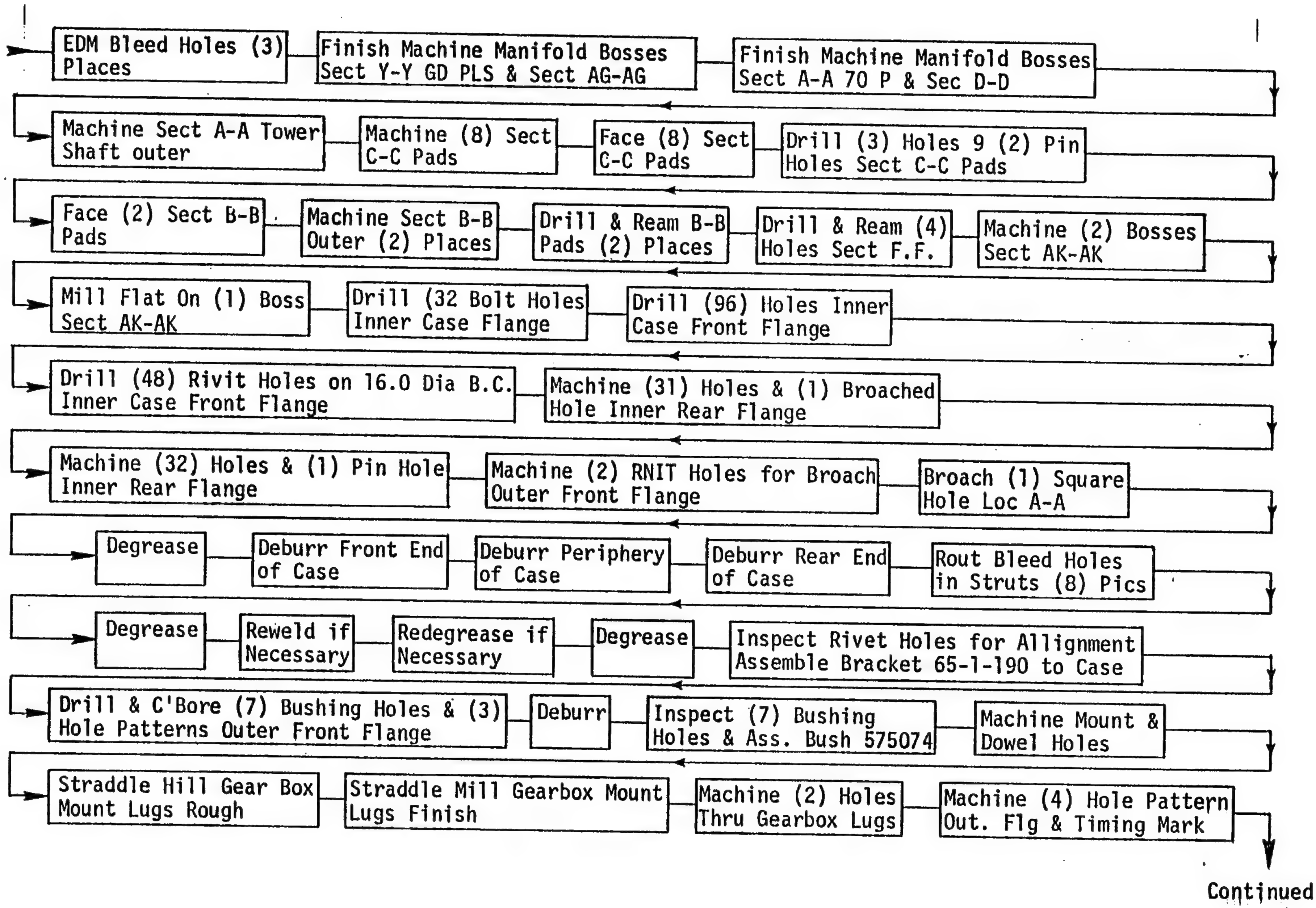


Figure D-20 TF30 DIFFUSER CASE - Fl Chart - Continued

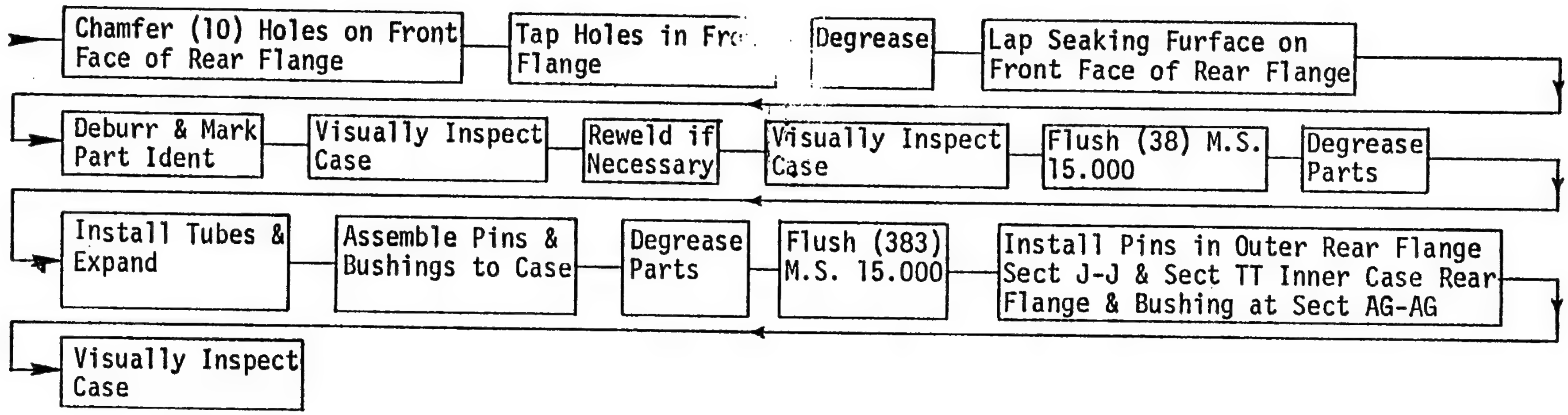
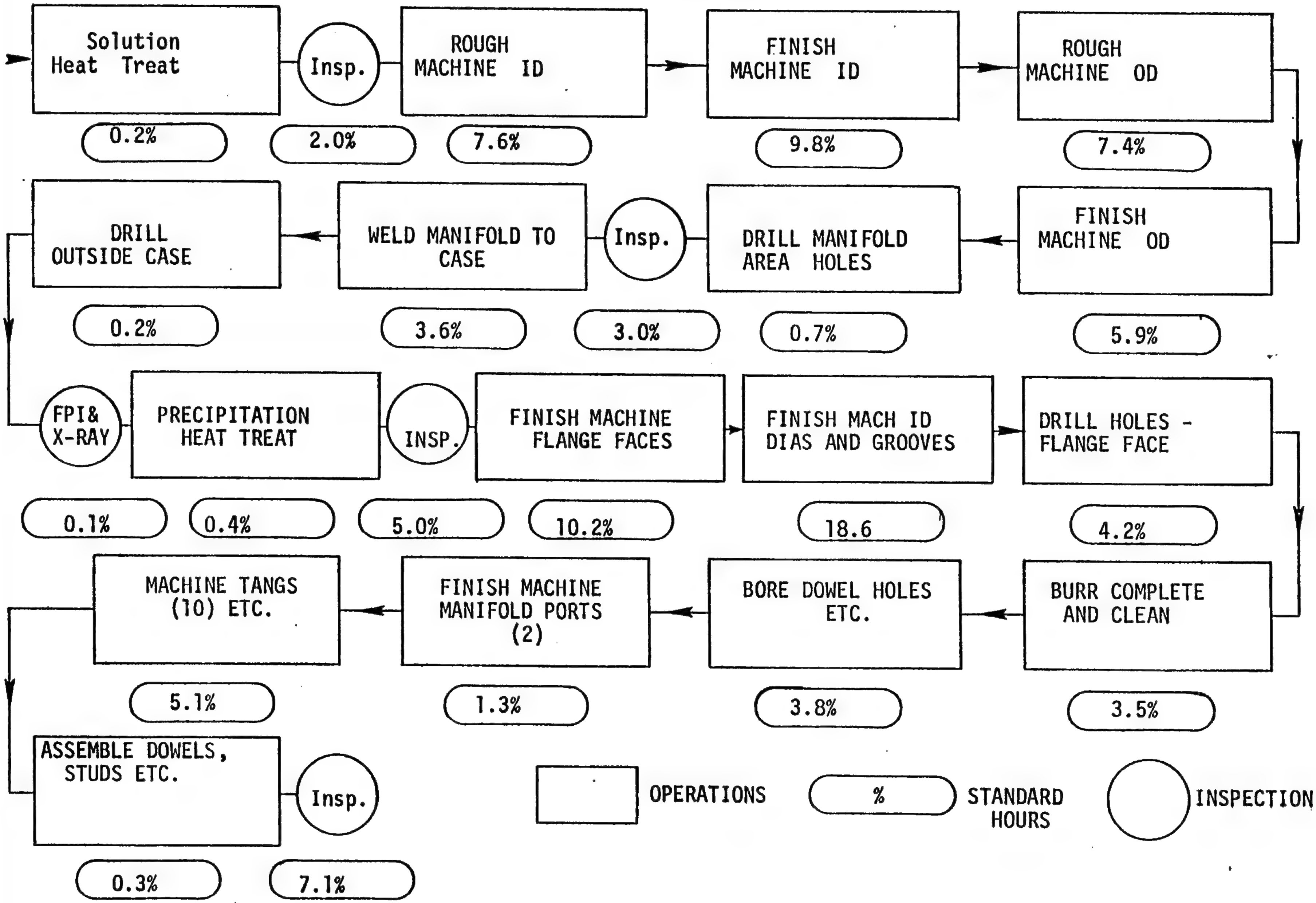


Figure D-21

TF41 - TURBINE CASE - Flow Chart



VIII. APPENDIX D-3 COMBUSTOR SUPPORTING DATA

PART NUMBER 710117 (BURNER CAN)

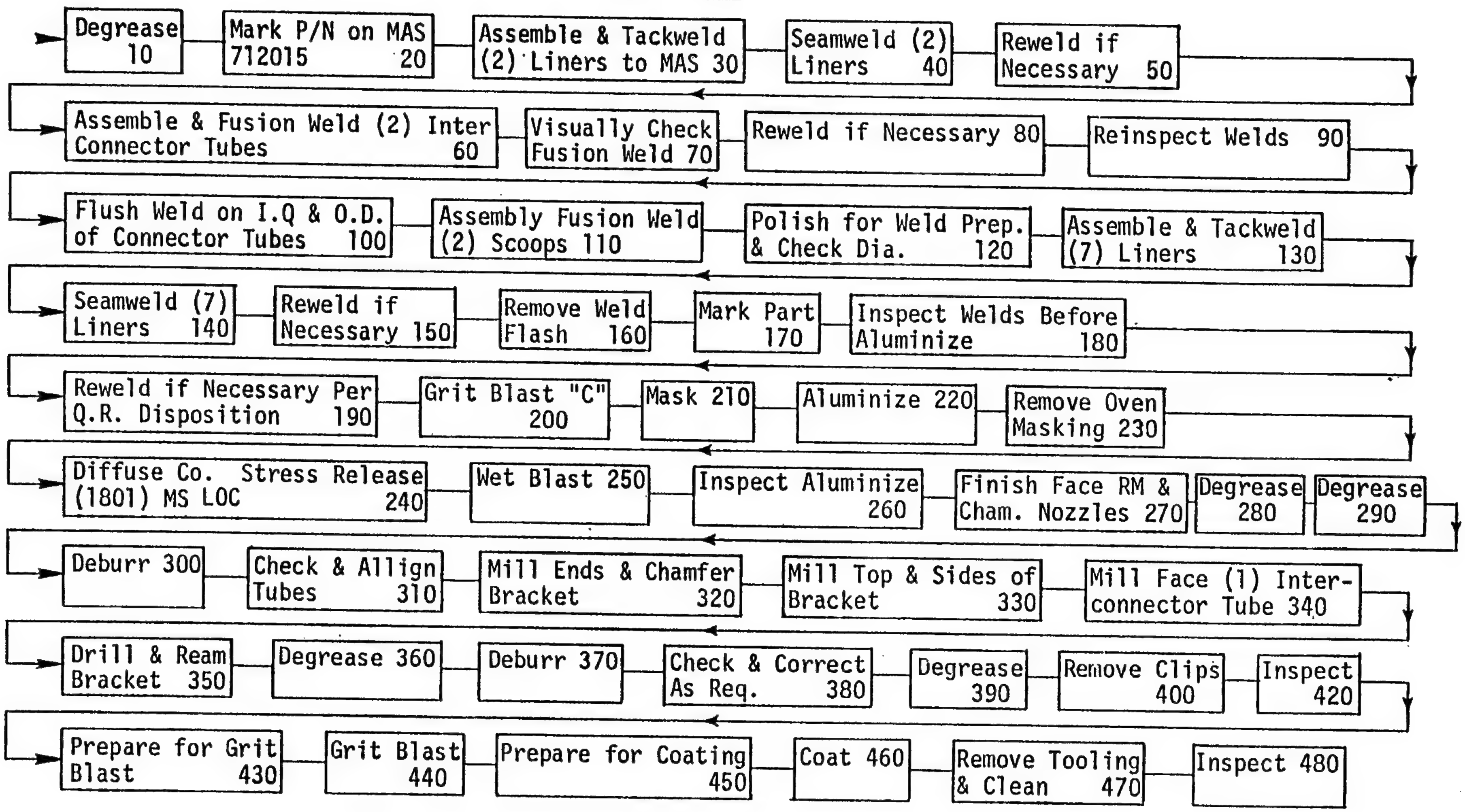
TF30, .5% Engine Cost

Operation No.	Description	Percent of Part Cost
10	Degrease	.182
20	Mark Part No. on MAS 712015	.050
30	Assemble and Tackweld (2) Liners to MAS	2.589
40	Seamweld (2) Liners	1.543
50	Reweld if necessary	.032
60	Assemble and Fusion Weld (2) Interconnector Tubes	2.389
70	Visually Check Fusion Weld	.258
80	Reweld if necessary	.115
90	Reinspect Welds	.026
100	Flush Weld on ID and OD of Connector Tubes	2.012
110	Assemble and Fusion Weld (2) Scoops	2.141
120	Polish for Weld Prep and Check Dia.	.674
130	Assemble and Tackweld (7) Liners	2.462
140	Seamweld (7) Liners	3.845
150	Reweld if necessary	.076
160	Remove Weld Flash	3.279
170	Mark Part	.110
190	Reweld if necessary per QR Disposition	.358
200	Grit Blast	2.012
210	Mask	.263
220	Aluminize ID	.700
230	Remove Masking	1.843
240	Diffuse Coat and Stress Relieve (1801) MS 1.000	.376
250	Wet Blast - N	1.791
270	Fin. Face/Rm. and Cham. Nozzles	1.561
280	Degrease	1.907
290	Deburr	.500
300	Deburr	.539
310	Check and Align Tubes	2.897
320	Mill Ends and Chamfer Bracket	3.716
330	Mill Top and Sides of Bracket	4.027
340	Mill Face (1) Interconnector Tube	1.448
350	Drill and Ream Bracket	.921
360	Degrease	.063
370	Deburr	2.173
380	Check and Correct as Req.	2.686
390	Degrease	.063
400	Remove Chips	.263

PART NUMBER 710117

Operation No.	Description	Percent of Part Cost
420	Inspect	.179
430	Prepare for Grit Blast	.632
440	Grit Blast	3.977
450	Prepare for Coating	1.251
460	Coat - Wear Coat	42.671
470	Remove Tooling and Clean	1.132

Figure D-22 - Manufacturing Flow Chart TF30 Combustor Can
P/N 710117



F101 COMBUSTOR

		PERCENT
TOTAL COST		100.0
Total Material Cost		59.27
Total Labor Cost		40.73
Sub Assemblies & Final Assembly Cost		
Outer Liner		21.74
Material	12.36	
Labor	9.58	
Inner Liner		17.31
Material	11.64	
Labor	5.67	
Dome		48.00
Material	33.09	
Labor	14.91	
Final Assembly		12.95
Material	2.18	
Labor	10.77	

TOTAL MATERIAL COST BREAKDOWN

Rings (R&W)	12.0
Turn	8.0
EDM	4.0
Fabrications	32.0
Braze	3.27

Figure D-23

Manufacturing Flow Chart - F101 COMBUSTOR

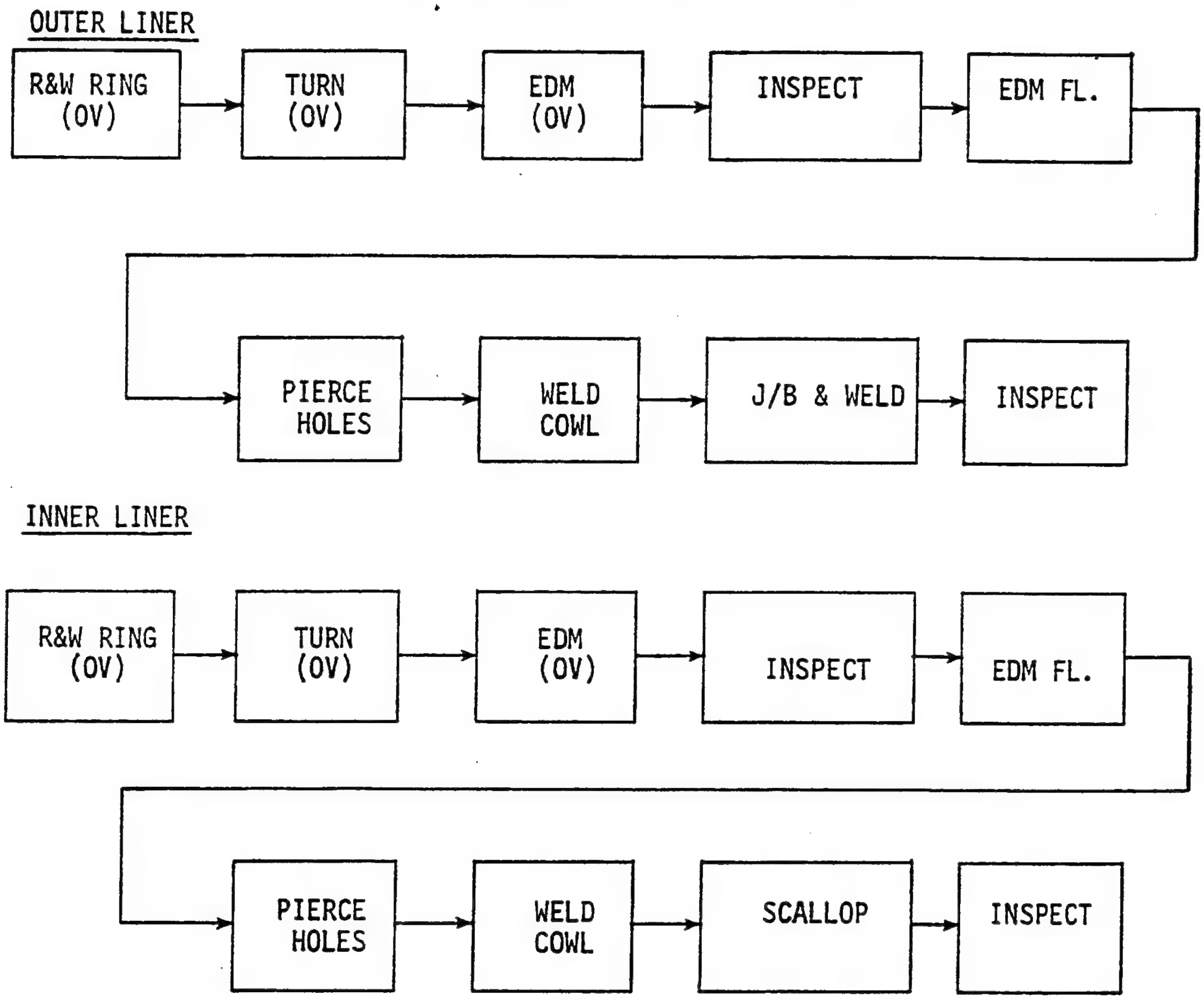


Figure D-24

Manufacturing Flow Chart - F101 COMBUSTOR

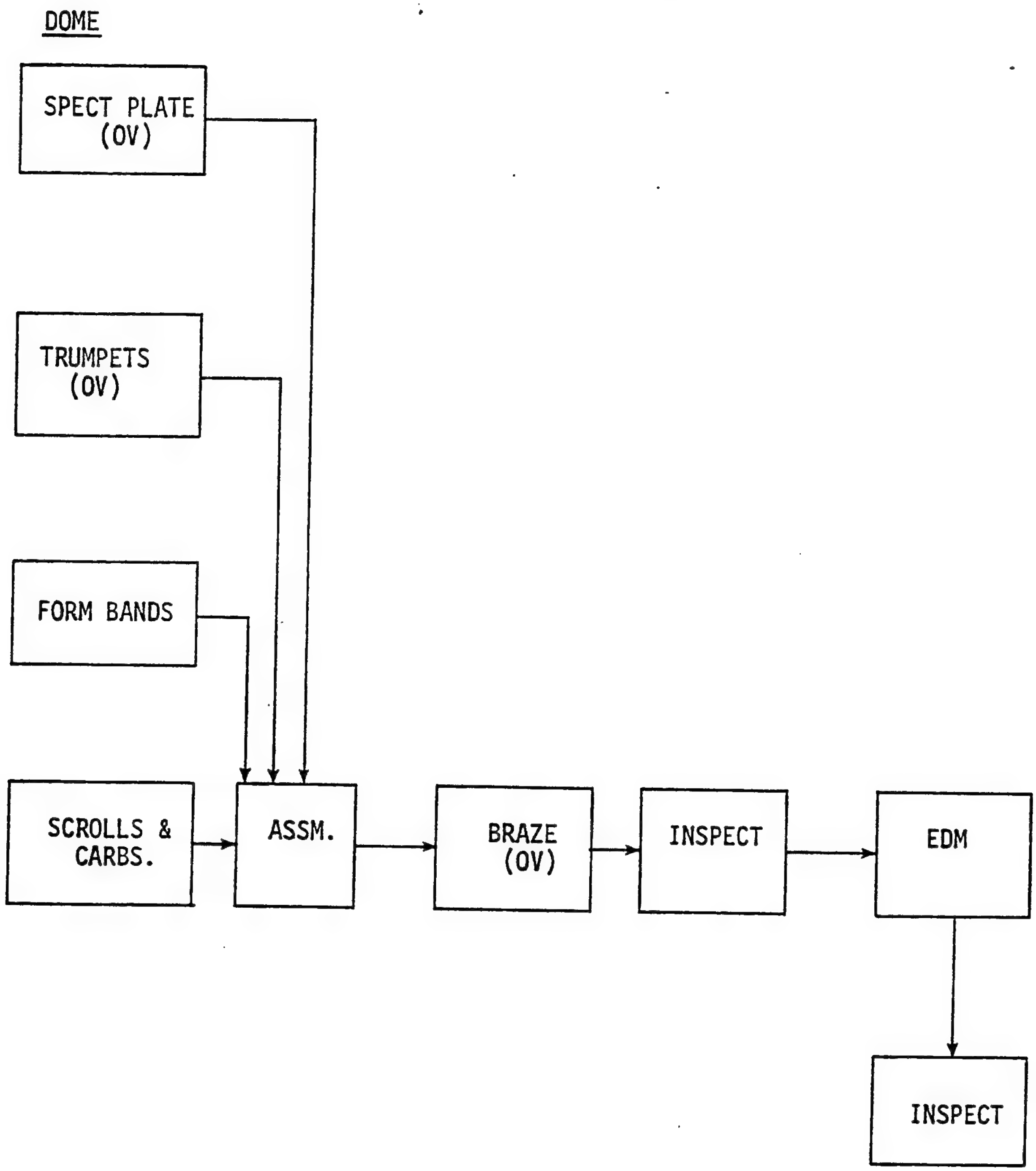
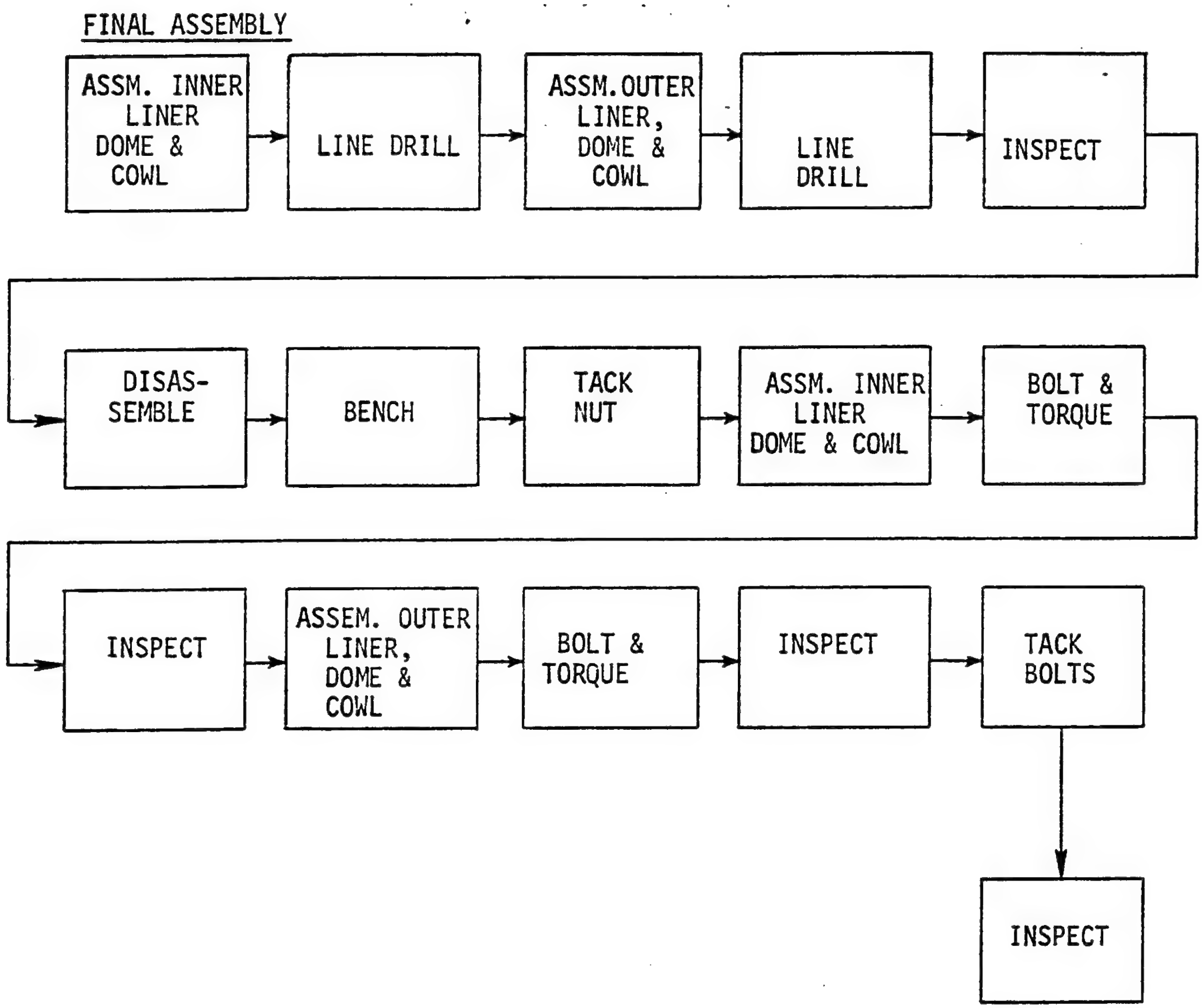


Figure D-25

Manufacturing Flow Chart - F101 COMBUSTOR



TF39 COMBUSTOR

		PERCENT
TOTAL COST		100.0
Total Material Cost (4.9% Casting)		35.21
Total Labor Cost		64.79
Subassemblies & Final Assembly Cost		
Outer Liner		26.76
Material	5.07	
Labor	21.69	
Inner Liner		19.72
Material	2.54	
Labor	17.18	
Dome		29.58
Material	9.58	
Labor	20.00	
Cowl		18.03
Material	18.03	
Labor	-0-	
Assembly		5.91
Material	-0-	
Labor	5.91	

Figure D-26

Manufacturing Flow Chart - TF39 COMBUSTOR

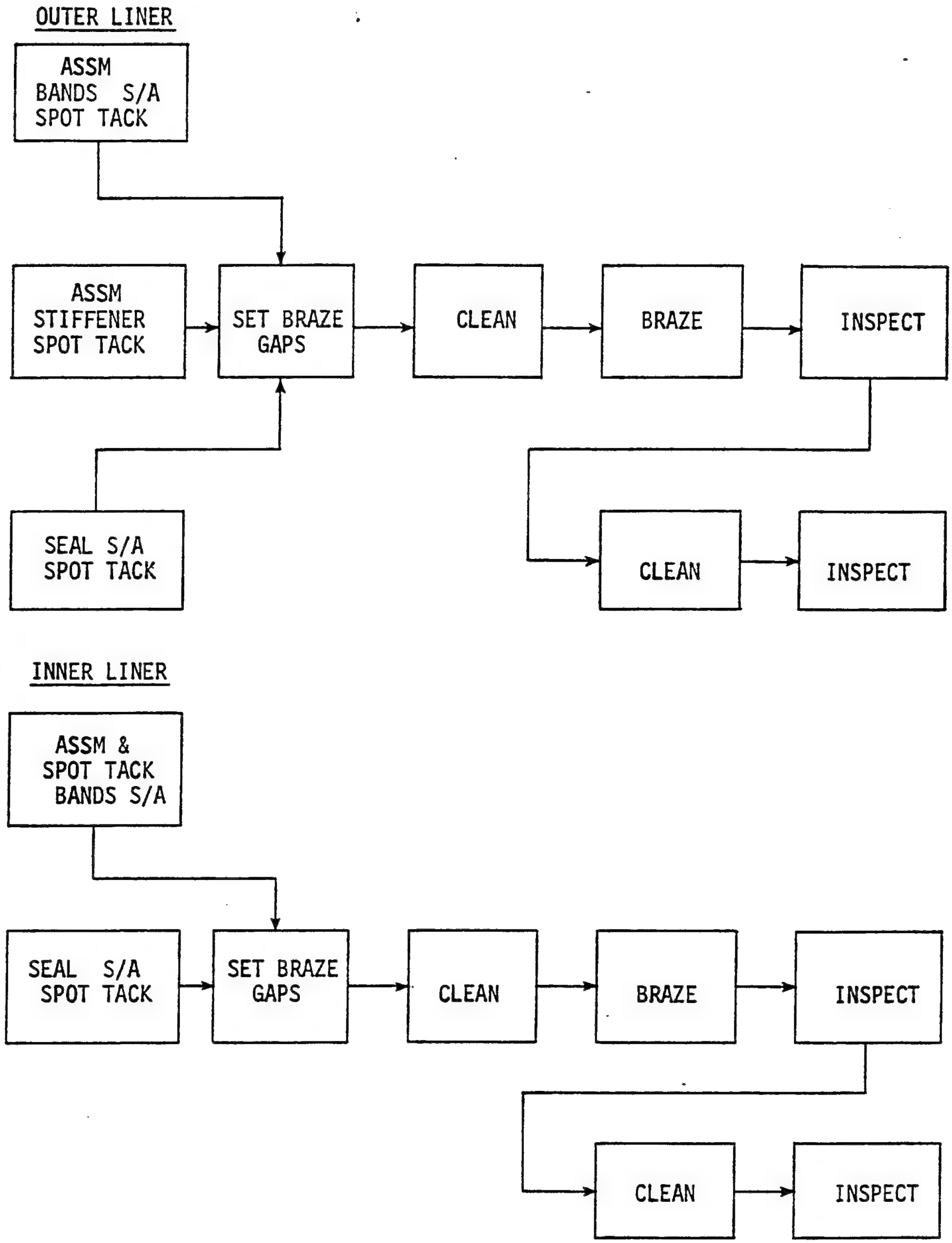
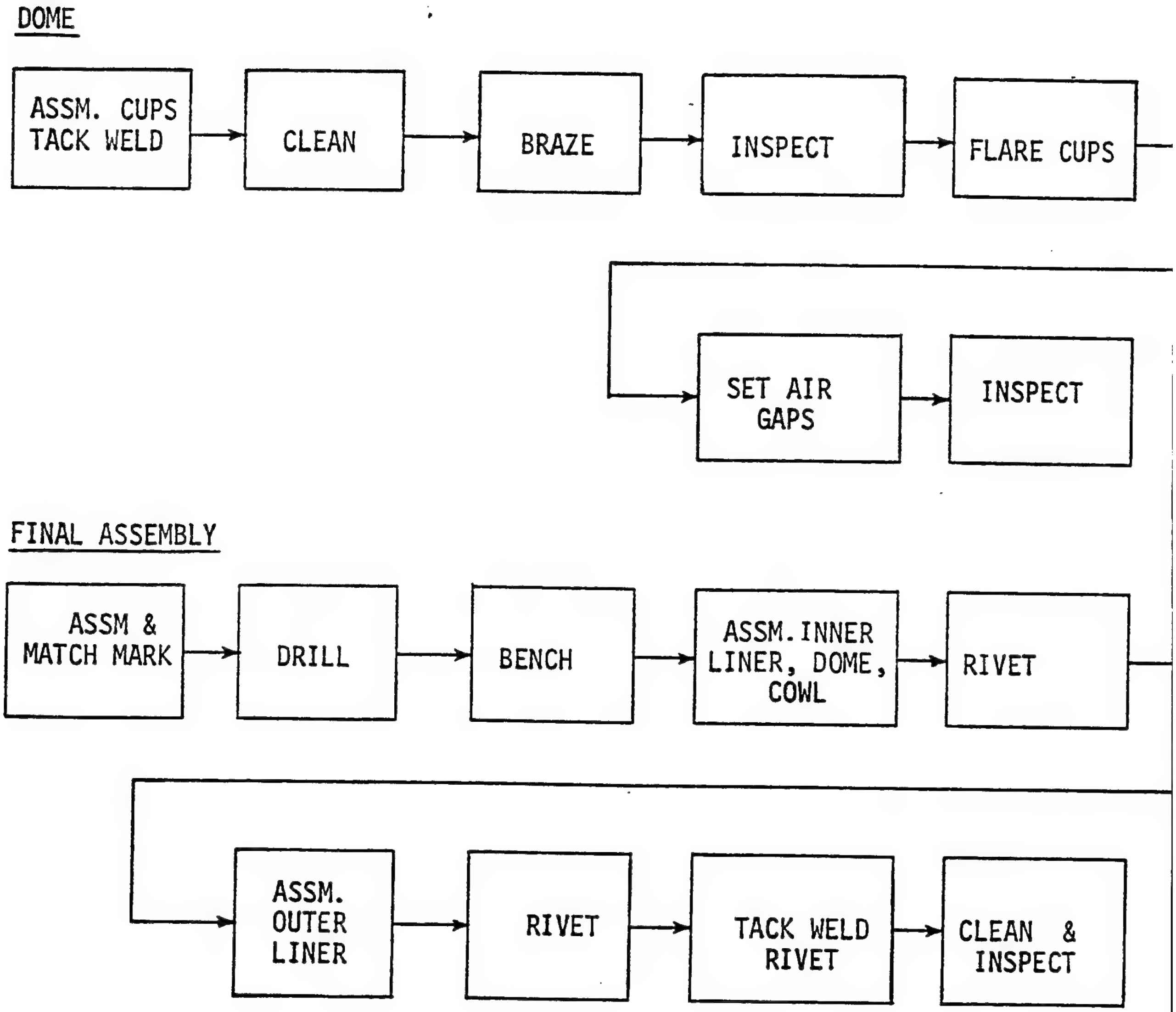


Figure D-27

Manufacturing Flow Chart - TF39 COMBUSTOR



J79 LOW SMOKE COMBUSTOR

	PERCENT
TOTAL COST	100.0
Total Material Cost 24% Forging (Inner Liner)	24.8
Total Labor Cost	75.2

No breakdown of subassemblies at present available.

WORK CATEGORIES BY PERCENT OF LABOR

(Labor of 75.2% Converted to 100%)

DRILL	EDM	TURN	JOINING (Br, EB, TIG)	PUNCH PRESS	BENCH	CLEAN & INSP.
3.7	19.4	15.0	20.6	14.8	21.9	4.6

For Total S/A & Final Assembly of J79 Low Smoke Combustor

J79 STANDARD COMBUSTOR

		PERCENT
TOTAL COST		100.0
Total Material Cost (34.9% Sheet Stock)		35.05
Total Labor Cost		64.95
Subassemblies & Final Assembly Cost		
Outer Liner		42.0
Material	7.95	
Labor	34.05	
Inner Liner		32.0
Material	15.70	
Labor	16.30	
Rear Liner		15.0
Material	9.60	
Labor	5.40	
Wear Ring		3.0
Material	1.80	
Labor	1.20	
Final Assembly (Labor Only)	8.0	

Figure D-28

Manufacturing Flow Chart - J79 COMBUSTOR - STD.

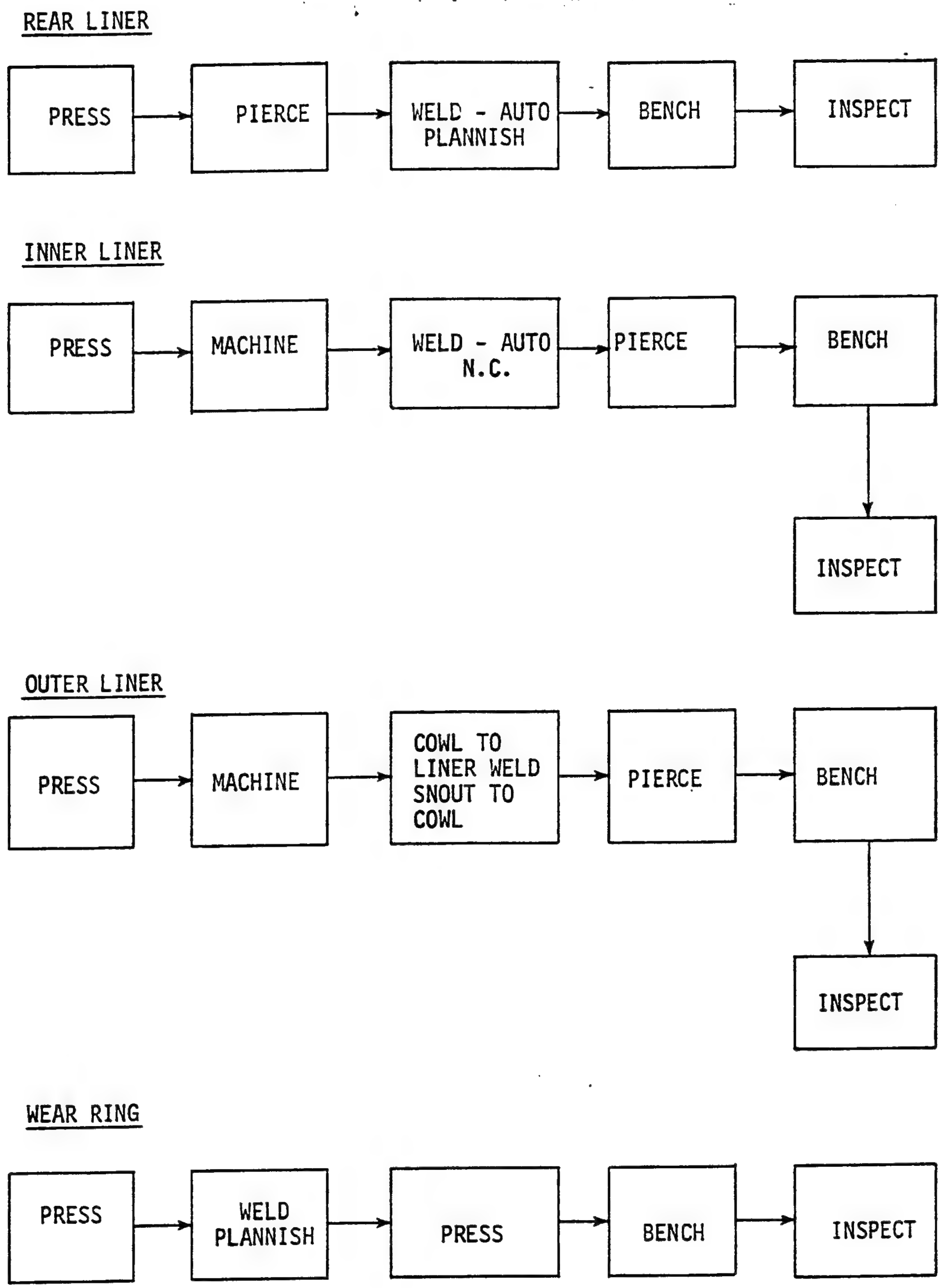
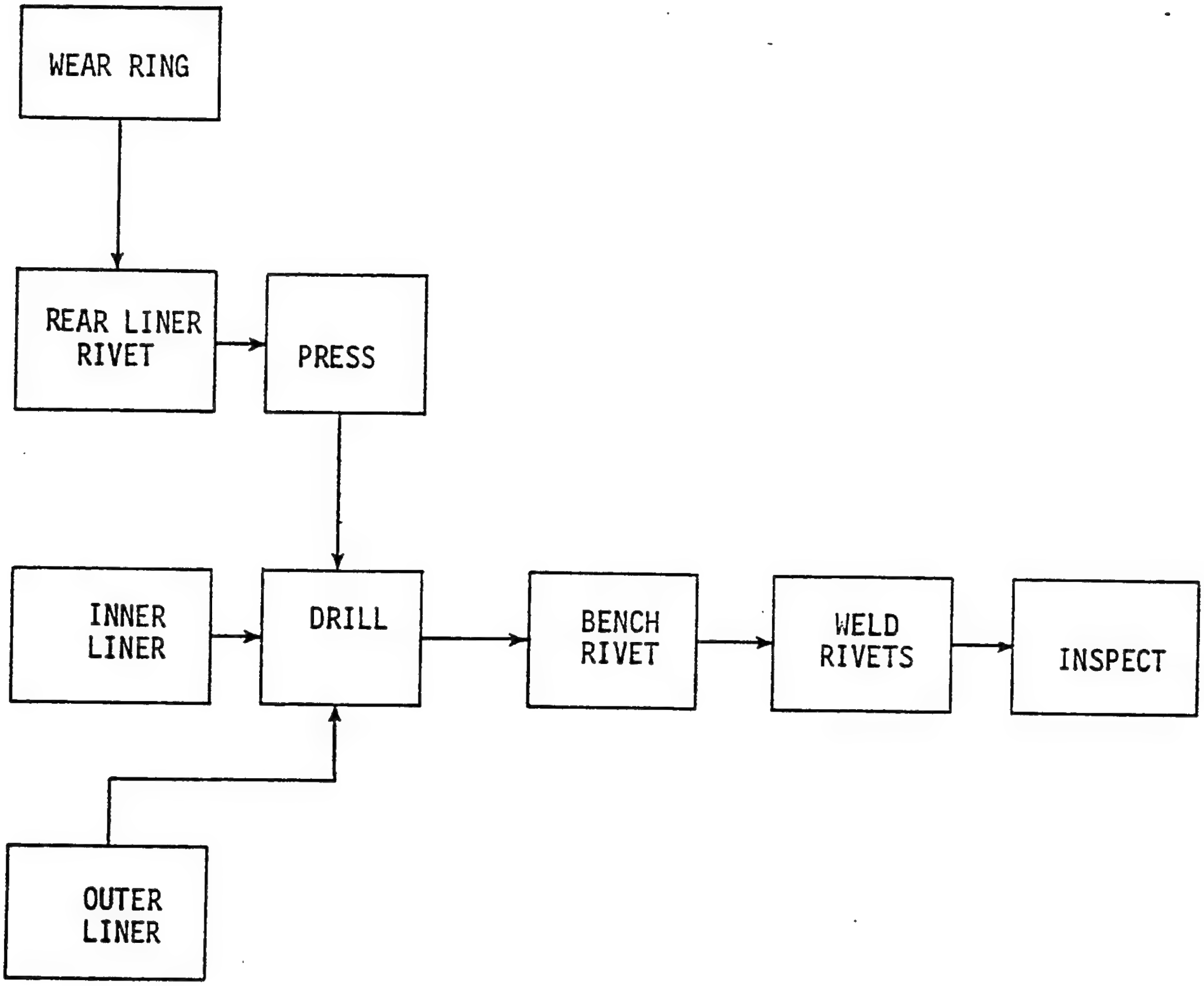


Figure D-29

Manufacturing Flow Chart - J79 COMBUSTOR - STD.

FINAL ASSEMBLY



IX. APPENDIX D-4 MACHINING

RECOMMENDATIONS

Short and Intermediate Range - Cost Reduction

1. Perform in-plant review of the specific parts studied by the committee. Explore potential for cost reduction within the following framework:

   a. Are current metal removal rates achieving the maximum practicable productivity level in keeping with current technology (tools, feeds, speeds, etc.)?

   b. Are required finishes, dimensional tolerances, tests, certifications and inspections actually in keeping with the technical needs of the components?

   c. Are there unnecessary redundancies in tests, certifications and inspections in b. above?

   d. Are there alternate manufacturing methods which offer a cost reduction potential?

   e. Does the anticipated production quantity justify specific cost reduction activity at this time?

2. Review manufacturing policies in general to ascertain whether specified tolerances and surface finishes are actually required for the design and structural needs of components. The cost reduction potential which has been developed from surface integrity studies should be carefully meshed with surface finishing requirements. Consideration should be given to zoning surfaces of parts to provide a high integrity surface only in

critically stressed areas. The overall policies regarding manufacturing practices/surface integrity should be reviewed to consider total effective component cost over the entire service life of the system under consideration.

3. Consider implementation of a program to develop deburring-radiusing procedures for large components. Variations of abrasive tumbling adapted to such components augmented by chemical or electrochemical action is suggested as a possible area of success.

Long Range - Cost Avoidance

1. Computer Aided Manufacturing (CAM)

The development of an effective CAM program is seen as absolutely essential to the achievement of minimum costs in future aerospace systems. Coordinated leadership of CAM development is now lacking. The requirements of an effective, generalized and coherent CAM development program lie beyond the scope and capability of any single industrial corporation or aggregate of industrial concerns. Such a program can be effectively undertaken only as an industry-government-university cooperative effort.

The needed CAM program goes beyond the concepts of computer aided design (CAD) and the utilization of direct numerical control (DNC) to machine tools. A total integrated program such as summarized in Table D-XI attached would seem appropriate for consideration.

2. Standardization of Specifications

Unified specifications for materials and process inspection should be developed. When available, significant economies in processing and

inventory can be achieved by both materials and hardware producers. Standardization of machine tool hardware and control systems mentioned elsewhere in this report would be accomplished within the development of the CAM system.

TABLE D-XI

CAM SYSTEM

ELEMENTS	DEGREES OF SOPHISTICATION
1. Design	Manual Drafting → Computer Drafting → NC (w/tape, & dwg.) → DNC (no ta[pe,] no dwg
2. Manufacturing Information Systems (MIS) - Software Packages, such as:	
Cost Analysis of Manufactured Product	Manual → Computer Simulation
Advanced Methods Planning	Manual → Computer Simulation
Machine Loading and Scheduling	Manual → Computerized
Production Control	Manual → Computerized
Materials Handling	Manual → Computerized
Numerical Group Technology (e.g., Variable Mission Concept)	- Computerized
Warehousing	Manual → Computerized
Direct Labor Reporting System	Manual → Computerized
Machinability Data System	Handbook → Computerized
Data System for Machines and Tooling	Handbook → Computerized
3. Hardware for Manufacturing	
Machine Tools	Conventional → NC → DNC
Adaptive Control	Conventional → NC → DNC
Materials Handling Systems (Pallets, conveyors, etc.)	Manual → Computerized
Inspection	Manual → Computerized
4. Hardware for Implementing Software Packages	
Computers	Mini → Large-Scale
Graphics	Alphanumeric → Vector Display
Data Entry Units	Manual → Interactive Console
5. Software for Operating Hardware	
NC Programming Support	AUTOSPOT → APT
Computer Languages	Assembly Language → FORTRAN, etc.
6. Interfacing Strategy	
Hardware	
Software	

X. APPENDIX D-5 NONDESTRUCTIVE TESTING

Typical costs and breakdown of operations has been shown earlier. The following is a discussion of these inspections. In general, the major cost is for labor through all inspections. The most obvious method of reduction is automation. Comments on automation are made for each inspection.

Radiography

The cost of radiographic inspection is almost totally in labor and film. The film costs on a typical radiographic inspection can constitute from 10% to as much as 60% of the total inspection cost. A number of techniques have been proposed to eliminate or reduce film costs. All of these techniques have lower resolution than film. Significant cost reductions could be made with the development of adequate substitutes for radiographic film.

The labor involved in radiographic inspection is principally in set-up and film reading. These two operations constitute 90% of the total time involved. Setup should be fairly responsive to automation if the quantity is sufficient. Film interpretation can be automated, but only with great difficulty at the present state-of-the-art.

Ultrasonic Inspection

Ultrasonic inspection is perhaps the easiest inspection to automate with sufficient quantity. It appears that little can be done to reduce costs at low production levels unless major changes in the technique are made.

Penetrant Inspection

Penetrant inspection labor can be divided into two major categories: part preparation and visual inspection. Each category requires approximately 50% of the effort at present. The part preparation should be capable of automation, even at present low production levels. The interpretation is much more difficult to automate. There are techniques available which are capable of interpreting penetrant indications automatically, however, these require large part quantities to be economically attractive.

Other Cost Factors

There are factors related to nondestructive inspection which produce significant added cost to the component but are difficult to evaluate quantitatively. These are discussed below.

Specification Proliferation - The material suppliers were almost unanimous in stating that the variety of specification for essentially the same material was a significant cost to them. This cost is incurred due to multiple testing, different set up requirements, larger inventory, and other intangible costs such as operator training difficulties and extra material handling costs.

The total impact is difficult to evaluate since the added costs are generally hidden. One sheet could be reduced 10% by standardized material requirements.

Duplication of Inspections - Inspection duplication is another "hidden" cost. This duplication principally occurs when parts are shipped from one company to another such that the supplier performs a final

inspection and the buyer performs a similar receiving inspection. A typical example of this added cost is in the case of the 6-2-4-6 titanium disk where duplicate material inspections between billet supplier and forger amount to approximately 1% of the final product cost. This cost could be at least halved by elimination of one inspection set.

The duplicate inspections are generally due to contractual or specification obligations so that responsibility for scrap can be determined. As such, the added expense may be difficult to eliminate.

Severe Specifications - The yield factors in material production are heavily influenced by specification severity. This is illustrated in the following table.

Effect of Specification on Yield
Normal Castings

Steel (no repair) Grade	Yield	Titanium (with repair) Grade	Yield
I A	50-60%	A	70%
I B	60-70%	B	80%
II A	85%	C	90%(1)
II B	90%	D	90%(2)

(1) 80% repair required

(2) 30% repair required

The yield factors relate directly to cost, although perhaps not linearly.

Specification severity is determined generally from stress and environment of the final product. Typically the specifications are made as realistic as possible. However, the area of specification requirement to material abilities has still not been adequately defined. Another

area which apparently has not been fully exploited is variable specifications, in which tight specifications are required only in the critical areas.

Part Preparation

Another cost factor which is not generally considered as inspection cost is the extra machining or other preparation procedures to allow inspection. This is most generally required for ultrasonic inspection. As an example, on a complex turbine disk of superalloy, an additional machining step is required to achieve an ultrasonic surface, which adds 11% to the manufacturing cost.

Two methods of reducing this cost are apparent. The first, and easiest, is to eliminate the early inspections (before large amounts of processing costs are expended). This can only be done when reject levels are low enough to make it economical.

The other method is to develop inspection techniques which are not as sensitive to surface conditions as those presently used.

Summary

1. The major cost in nondestructive inspection is labor. Any method which reduces the labor expended would help the cost picture. The most obvious method is automation, however, this must be done with care since the quantity must be enough to justify the capital investment. Areas where automation seems most feasible are: radiographic setup, ultrasonic inspection (total), and part preparation (cleaning, application of penetrant, removal of excess penetrant, application of developer) in penetrant inspection.

2. Development of effective, low cost, substitutes for film could reduce radiographic costs significantly. Typically, the film costs are from 10 to 60% of the cost of radiographic inspection.

3. Other cost reductions would be possible with reduction of number of specifications, inspection duplication, severe specifications, and part preparation for inspection.

TYPICAL COSTS
PENETRANT INSPECTION

Penetrant inspection is almost totally a hand operation. As such, the labor costs are generally high and the equipment and material costs low. The steps involved in a typical operation are shown in Table D-XII.

Inspection Time

The inspection time is a function of the part size, complexity, and specification severity. Typical times are shown below.

Wheels, Compressor or Turbine	10 minutes
Blades, Compressor or Turbine	3 minutes per inspection
Diffuser case	
Details	1 hour
Assembly	20 minutes
Intermediate Compressor Case	30 minutes per inspection
Combustor	5 minutes per inspection

Equipment and Material Costs

The material costs are almost negligible, particularly if care is taken to conserve liquids by draining.

Equipment consists mainly of tanks for preparation and dipping and the booth and black lights for inspections. Costs vary from $15,000 for a standard size to $30,000 for large capacity tanks for immersing large parts.

TABLE D-XII

OPERATIONS IN PENETRANT INSPECTION

Operation	Description	Est. % of Operator Time
Cleaning and Scale Removal	The surface must be free of all dirt, grease, and scale. Operations can involve grit blasting and vapor degreasing or similar cleaning operations.	10
Application of Penetrant	The penetrant is applied generally by dipping the part in a tank. Typical penetration times vary from 5 to 30 minutes.	10
Removal of Surface Penetrant	Excess penetrant on the surface must be removed. This removal is accomplished by water wash with water soluble penetrants or emulsification and water wash with oil based penetrants. Emulsification times can vary from 10 seconds to 5 minutes.	20
Application of Developer	Developer is a powder generally applied by hand using either a brush, hand powder bulb, or powder gun. The developer period should equal approximately one half the penetration time.	10
Visual Inspection	Visual inspection is generally performed under black light in a darkened area. Proper inspection may involve further Application of penetrant or developer and the use of magnification.	50

TYPICAL COSTS

RADIOGRAPHIC INSPECTION

The costs of a Radiographic Inspection are mainly in labor and film. The steps involved in a typical operation are shown in Table D-XIII.

Inspection Time

The inspection time is a function of part size, complexity, number of separate exposures required and specification severity. Typical times vary from 7 to 36 minutes per film required. Some representative times are shown below.

	Labor	Film Costs
Compressor Blade	7 min (4/film)	$0.30
Turbine Blade	3 min (12/film)	0.10
Diffuser	2.5 hours	10.00
Intermediate Compressor Case	10 hours (85 rad)	80.00

Equipment and Material Costs

X-ray film is the major cost at from $1 to $1.25 per film. Chemicals and water for development are not generally a significant cost. The equipment costs are shown below.

X-ray Machine	$8,000 to $10,000 (250-300kv)
Automatic Film Processor	12,000
Special Shielded Room, other equipment	10,000 to $100,000 depending on complexity

TABLE D-XIII

OPERATIONS IN RADIOGRAPHIC INSPECTIONS

Operation	Description	Est. % of Operator Time
Set up	The part must be positioned between the x-ray device and film in a manner such that proper areas are inspected. Special fixtures and masks are sometimes used to facilitate inspection.	55
Exposure	The x-ray device is activated for times from 1 to 5 minutes typically.	5
Film	Most film development is done automatically although hand processing is sometimes used.	5
Film Reading	The film is inspected for evidence of flaws using either aided or unaided visual techniques.	35

TYPICAL COSTS

ULTRASONIC INSPECTION

Ultrasonic inspection costs are, generally, labor and equipment. No material costs of any significance are generally incurred. The inspection is usually performed by a hand or semiautomated technique with the interpretation of the results made at the time of inspection. Calibration of the equipment can be a significant cost depending on the severity of the inspection criteria. Typical calibration times vary from less than 1% to sometimes over 30%.

Inspection Time

The inspection time is primarily a function of part size, degree of specification severity, and amount of automation available. Typical time for minimal automation is shown below.

Wheels	45 minutes
Intermediate Compressor Case	1.5 hours

Equipment Costs

No material costs of any significance are generally incurred. Typical equipment costs are shown below

Ultrasonic Electronic Equipment	\$8,000 - \$10,000
Tanks, Recorders, and Scanning Mechanisms	\$5,000 - \$30,000 (1)
Positioning Fixtures	0 - \$100,000 (2)

(1) Depending on size and degree of complexity
(2) Depending on amount of automation

XI. APPENDIX D-6 SUPERALLOY PRODUCER

In considering cost reduction possibilities in superalloy mill products, it is well to keep in mind that the present business climate in the Superalloy Industry is not conducive to the large capital investments required for maximum cost reduction potential. Secondly, recent reductions in Corporate R&D funding, which in some Companies have led to the complete elimination of superalloy R&D programs, will reduce the rate at which the industry will be able to affect future cost-reductions through process improvement.

At present producers of wrought superalloys are operating with little profit. It is believed that no superalloy manufacturer is enjoying profits in excess of 2% of sales and more than one is operating at a loss. In the last three years, Cameron Iron, Eastern Stainless Steel, Vasco and Allvac have ceased to produce superalloy sheet products, and Fansteel has closed their Baltimore plant for dispersion strengthened alloy products. In addition, it is likely that one other supplier of superalloy sheet will soon withdraw from this product line.

The Superalloy Industry is facing a high rate of rising costs, in an economic situation of declining market size and negligible profits with a resultant lack of capital investment funds.

In the last four years the price of raw materials has increased drastically. The price of the more common alloy constituents has increased as follows: Ni-41.5%, Co-19%, Cr-32%, Mo-5%, V-20%, W-25%, Si-7%, Cb-12% and Mn-12%. In addition, it is expected that during 1973 the

sales price of nickel will increase from \$1.33 to \$1.58/lb and cobalt from \$2.17 to \$2.45/lb. As shown in Table XIV the pattern of increasing nickel costs is particularly critical.

Simultaneously with the above raw material cost increases, the superalloy industry must cope with increased labor (5-6% per annum, see Table XV) and utility costs (approximately 8% per annum).

Although the introduction of improved processing, more efficient inventory systems, and closer quality control have allowed the industry to increase productivity, these increases in efficiency are now jeopardized by a cost structure that does not allow sufficient investment. In the last four years the cost of superalloy sheet products has increased by some 10-15%. If a more equitable sales price structure cannot be negotiated for superalloy wrought products the number of suppliers as well as the economic viability of those remaining in this market will be weakened to the point that large cost increases will have to be faced.

THE ECONOMICS OF SUPERALLOY PRODUCTION

On the average, the works costs of superalloy sheet production are distributed as follows, 65% direct materials, 30% variable costs (labor, maintenance, etc.) and 5% testing and quality control. This approximate breakdown does not include costs of inventory maintenance, corporate or fixed overhead or cost of sales and R & D. Even this simple breakdown, however, clearly identifies material costs as the main factor in the works cost of sheet production.

The production of superalloy sheet (see Table XVII) is a low yield process and thus highly sensitive to material cost. For a typical

0.040" x 36" x 96" sheet product few alloys can be processed with yields exceeding 50% of initial electrode weight. Yields to sheet as low as 25% are common for many of the higher strength alloys.

A breakdown of the variable costs involved in the production of typical superalloy sheet products is shown in Table XVI. This breakdown reflects only production labor and expense costs but serves to illustrate that no single operation is responsible for more than about 20% of the variable cost, which in turn is approximately 30% of the total works cost. The relatively large cost of grinding and conditioning, however (14% to 20%) should be noted, particularly since these procedures carry with them yield reductions.

In summary, it is obvious that in the production of superalloy sheet cost reductions are best achieved through the introduction of processes, composition and quality controls which improve yields or reduce material costs. In addition, it is well to keep in mind that a superalloy mill generates large amounts of internal scrap whose efficient recycling in the process is the easiest method of controlling material costs.

Cost reductions in the production of wrought superalloy products and, particularly, sheet where low yields are often encountered are best achieved by:

1. Development of primary melting practices which can utilize scrap and inexpensive forms of alloy additions.
2. Development of electrode casting, remelting, forging and hot rolling practices which maximize yields by producing structural conditions of maximum ductility and uniformity and allow processing of products with minimum grinding or conditioning and material loss.

TABLE XIV

NICKEL PRICES

Jan. 53 - Nov. 54	63.08 cents/lb.
Nov. 54 - Dec. 56	64.50
Dec. 56 - June 61	74.00
June 61 - May 62	81.25
May 62 - Sept. 65	79.00
Sept. 65 - Oct. 66	77.75
Nov. 66 - Sept. 67	85.25
Sept. 67 - Dec. 68	94.00
Dec. 68 - Nov. 69	103.00
Nov. 69 - Oct. 70	128.00
Oct. 70 - Dec. 71	133.00

An additional increase of up to 25 cents/lb is expected in 1973.

TABLE XV

HOURLY EMPLOYEE COSTS U. S. STEEL INDUSTRY

1960	$3.82
1961	3.99
1962	4.16
1963	4.25
1964	4.36
1965	4.48
1966	4.63
1967	4.78
1968	5.03
1969	5.38
1970	5.68

TABLE XVI

LABOR AND VARIABLE EXPENSE COSTS FOR 0.040" x 36" x 96" SUPERALLOY SHEET

	A Soln. Str. Ni Base %	B Ppt. Str. Ni Base %	C Ppt. Str. Ni Base %	D Soln. Str. Co Base %
Primary Melting	8.6	20.9	14.4	6.4
Secondary Melting	8.7	7.1	4.5	6.9
Forging	4.7	4.2	3.1	3.9
Hot Rolling	13.1	12.8	17.3	13.2
Coil Buildup	6.7	6.5	4.8	7.2
Cold Rolling	9.6	11.6	12.1	13.5
Annealing	18.3	7.4	7.9	15.5
Slitting and Shearing	6.7	5.0	3.2	6.4
Grinding (various)*	14.2	15.7	19.7	16.2
Inspection, Testing, etc. Pickling	9.4	8.8	12.0	10.8

* Performed primarily after forging and hot rolling.

TABLE XVII

PROCESSING
OF
SUPERALLOY SHEET

1. Primary Melting. Vacuum induction or air melting. 20,000 - 30,000 lb. heats cast into 10,000 lb. electrodes.

2. Secondary Melting. Electroslag or vacuum arc remelting.

3. Forging to sheet bar (5" x 18" x 22").

4. Conditioning and grinding.

5. Hot Rolling. On 3-Hi mill to 0.375" followed by 2-Hi mill to 0.150".

6. Weld (37" x 184" x 0.150") hot rolled sheet into continuous coil on coil. Build-up line.

7. Cold roll in one or more sessions on 100 MKW Schloemann mill with intermediate annealing if required.

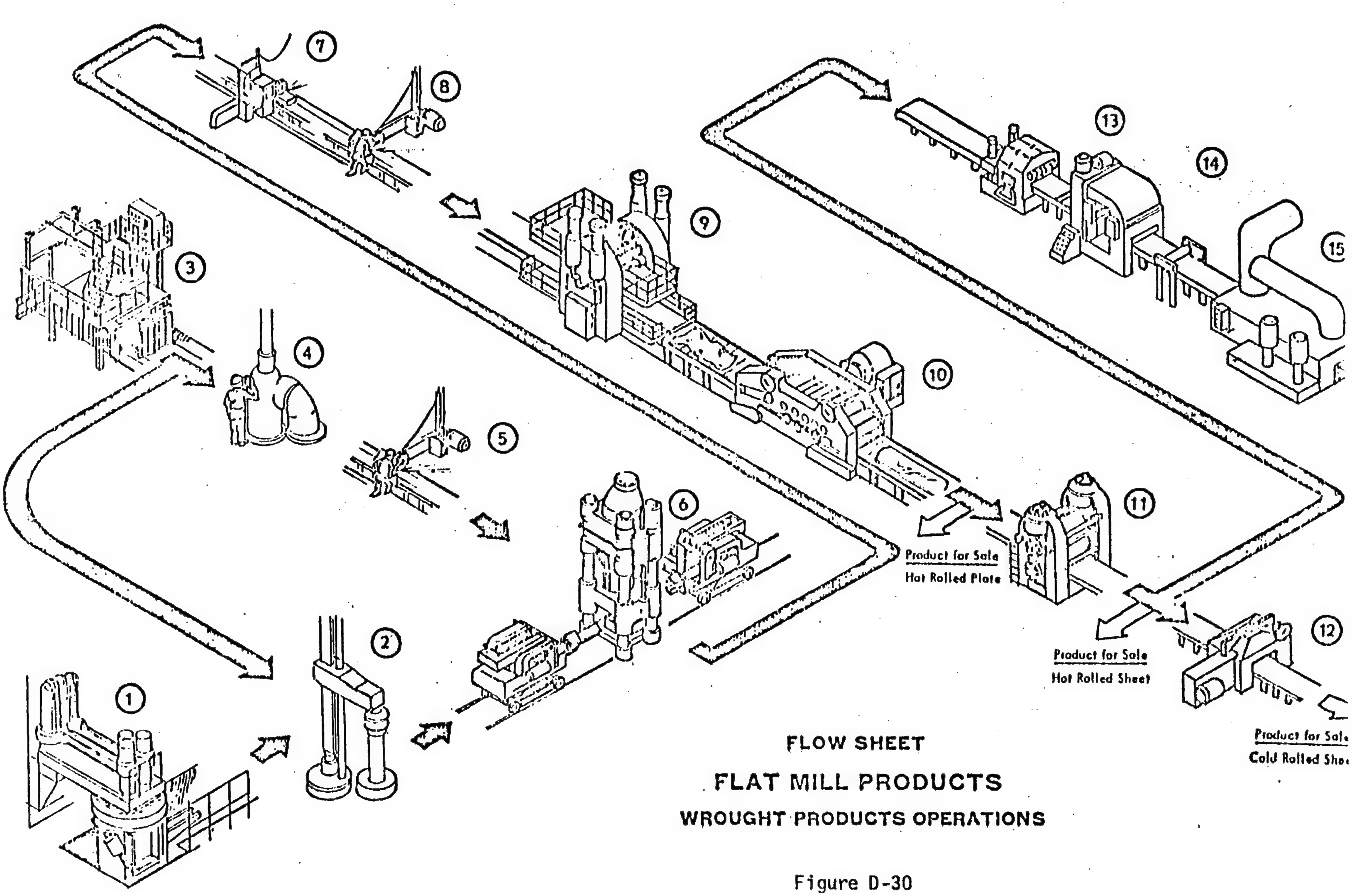
8. Bright anneal in continuous, H_2 atmosphere, furnace.

9. Slit and shear removing welded areas.

10. Pickle, inspect, test.

FACILITIES REQUIRED FOR
FLAT MILL PRODUCTS

1. 5-Ton and 15-Ton Air Melt Furnace and 5-Ton Argon-Oxygen Converter
2. Electroslag Remelting Furnace
3. 10-Ton Vacuum-Induction Melting Furnace
4. Vacuum-Arc Furnace
5. Ingot Conditioning
6. 2000-Ton Forgi[illegible] [illegible]ress
7. Slab Grinding
8. Slab Cut-off
9. 3-Hi Hot Rolling Mill
10. Plate Roller Leveler
11. 2-Hi Hot Rolling Mill
12. Sendzimir Cold Rolling Mill
13. Sheet Roller Leveler
14. Shear and Welder
15. Scrubber
16. Edge Trimmer
17. Grinder
18. Drag Stand
19. Coiler
20. 100 MKW Schloemann Mill
21. Welder
22. Scrubber
23. Bright Annealing Furnace
24. Coiled Strip Slitter
25. Flat Sheet Slitter and Shears



FLOW SHEET

FLAT MILL PRODUCTS

WROUGHT PRODUCTS OPERATIONS

Figure D-30

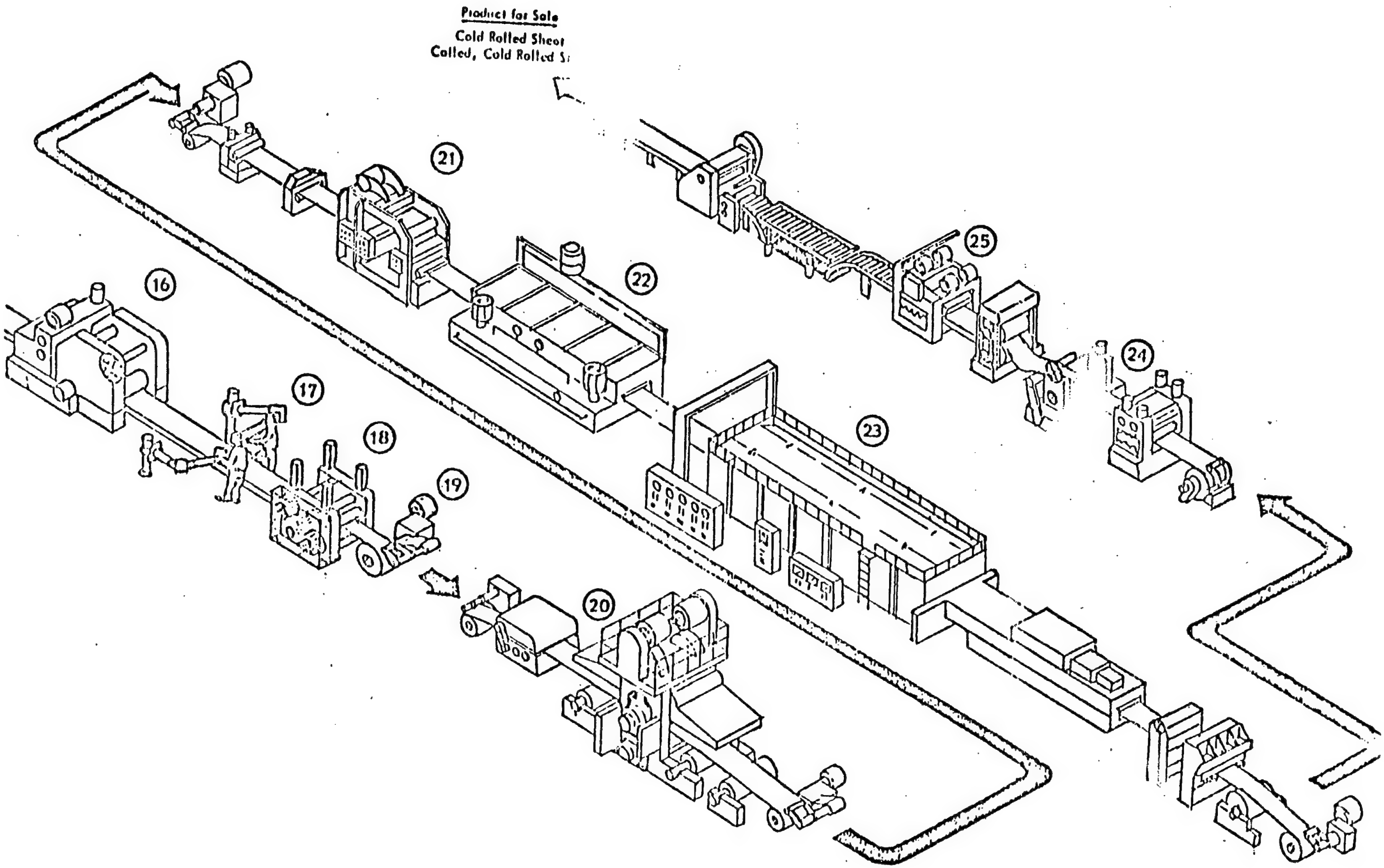


Figure D-30 (Continued)

COST REDUCTIONS IN SUPERALLOYS

Actions which will lead to reduced costs in superalloy production can be broken down into two categories: Improved Specification and Standardization, and Development of New Technology. Brief summeries of these points for each category are listed below:

1. Improved Specification and Standardization

a. Superalloy sheet, though bought on a weight basis, is utilized on an area basis. Effective gage control is thus one method of increasing the number of parts that can be made from a lot of sheet. Improved gage control at the mill, however, requires greater standardization of sheet gages, much as is practiced by the steel industry. The present practice of ordering sheet to any desired thickness requires frequent changes in production mill settings, with each change introducing control adjustments.

b. Proliferation of specifications should be reduced wherever possible, especially if such specifications require different processing or annealing procedures that increase scheduling and inventory costs with negligible effect on properties.

c. Improved and additional primary standards for chemical analysis should be established. The National Bureau of Standards has available only two or three primary analytical superalloy standards. For the case of trace element analyses, no standards exist.

d. The present trend of specifying minimum limits for trace elements on the basis of limited data should be re-evaluated. Once set, such specifications will be difficult to change. Without reliable and standardized analytical techniques, standards, and sampling trace element specifications set today could become meaningless, yet still binding, in the future.

e. Centralization of alloy property data and sponsorship of data generating programs should be promoted. Present tendency for each material supplier and user to generate his own data and treat it as proprietary information, which is rarely shared, adds an appreciable factor to increasing engine costs and reduces reliability of design.

f. Utilization of ESR superalloys is now limited to static parts due to the historical double vacuum melting requirement specified for rotating parts. Lower processing costs and superior cleanliness can be achieved by ESR for many compositions. The artificial limitation of ESR materials to static parts should be lifted as soon as possible.

2. Development of New Technology for Cost Reduction

a. Primary melting techniques capable of producing superalloys to acceptable chemistry standards, including trace metal specifications, while utilizing lower virgin metal charges, are required.

b. Secondary melting techniques should be developed in production sizes, capable of producing shapes that will increase yields or reduce conditioning in subsequent processing to wrought products. ESR hollows is one example.

c. Utilization of thinner gages is the pattern for future sheet products. Weight and cost reduction considerations force this trend. Maximization of processing schedules and development of improved gaging controls are required before superalloy sheets in the 0.020" to 0.010 range can be effectively and economically produced.

d. The generation of net shapes by shear spinning and deep drawing techniques is one attractive approach for achieving material cost reductions. The uniformity and reproducibility of properties in cross-rolled plate make this product preferred over forgings or normal plate as the starting material for complex forming operations. In addition, cross-rolling is one of the most suitable processes for the performance of controllable thermo-mechanical processing sequences which can maximize ductility, formability and toughness in high strenth alloys. Programs on the utilization of cross-rolled plate in the generation of net shapes can thus be recommended.

e. In the U.S. approximately 10×10^6 lbs of contained nickel is lost each year in metallurgical and grinding/machining scrap and wastes unsuitable for use as a melting charge. Chemical re-cycling processes have been identified by the U.S. Bureau of Mines that should be capable of recovering the nickel in such wastes as well as the associated cobalt, chromium, tungsten and molybdenum contents. Continuation of such programs to pilot plant evaluation is recommended for obvious economic, material conservation and ecological reasons.

f. Development of alloys to reduce metal costs should be considered. This can be achieved through compositions that allow ready utilization of scrap or reduce the utilization of expensive alloying elements. The development of Inconel 706 is one good example of what can be achieved.

THE SUPERALLOY SCRAP PROBLEM

Initial estimates indicate that the total net poundage of contained nickel in U.S. superalloy scrap not presently suitable for direct remelting approaches 10 X 10^6 lbs/yr. This figure does not include other miscellanous superalloy waste whose estimated nickel content is: metallurgical smokes 400,000 lbs/yr, pickle liquor sludges 200,000 lbs/yr; and EDM and ECM sludges, or mill scale, whose nickel contents cannot be quantitized at this time but obviously contain appreciable superalloy metal.

At present, the approximately 10 X 10^6 lbs of contained nickel present in these unusable wastes and scrap is lost to the U.S. A fraction of the grindings, perhaps as much as 6 X 10^6 lbs/yr is shipped to Japan where Kawaguchi Seiko Co. recovers approximately 60% of the total contained nickel and cobalt through an electric furnace smelting process, producing an iron-nickel-cobalt alloy suitable for the steel industry.

..e to the sensitivity of superalloy products to raw material costs, the upgrading of waste and scrap products presently unsuitable for remelting would supply a needed economic leverage in stabilizing raw material costs. In addition, ecological problems existing in the disposal of many of these wastes are rapidly becoming more pressing.

Chemical treatment processes have been developed by the U.S. Bureau of Mines which appear to be feasible for the extraction of not only nickel and cobalt but possibly chromium, tungsten and molybdenum from, heretofore, useless waters.* Although the Bureau of Mines process requires full-

* U.S. Bureau of Mines, RI 7316, "Chemical Reclaiming of Superalloy Scrap" November 1969.

scale pilot plant verification, its economic feasibility appears to be promising, particularly if the present rate of raw material price increase continues.

XII. APPENDIX D-7 DESIGN

Engine designs can be placed into 3 categories as segregated by time.

1. Current engines - These presently in service for which logistics of spare parts influence changes in design. Cost reduction manufacturing changes might be applicable.
2. New engines - Those presently being designed but not yet in service or prototype. Cost reduction manufacturing changes should be applicable.
3. Future engines - Those not yet defined by aircraft mission and engine cycle. These engines can be expected to incorporate new technology in various degrees but similar functions of parts can be anticipated. Higher pressures, higher temperatures and higher thrust levels might require an advancement in superalloy properties and more non-traditional manufacturing techniques but many of the cost reduction manufacturing procedures developed for the current and new engines should also be applicable to future engines.

XIII. APPENDIX D-8 TITANIUM CASTING

There are several areas where considerable cost reduction can be accomplished by the Air Force. These areas require additional study as follows:

1. Powder Metallurgy - The incorporation of Ti-6Al-4V powder metallurgy components can have the same effect in lowering costs as the incorporation of other powder metallurgy components. The process simplification is shown in the attached flow diagrams of a "seal ring-transfer tube." The results of this change reflect no change in property levels, upgrading of surface and X-ray specifications, and 50 percent decrease in price.

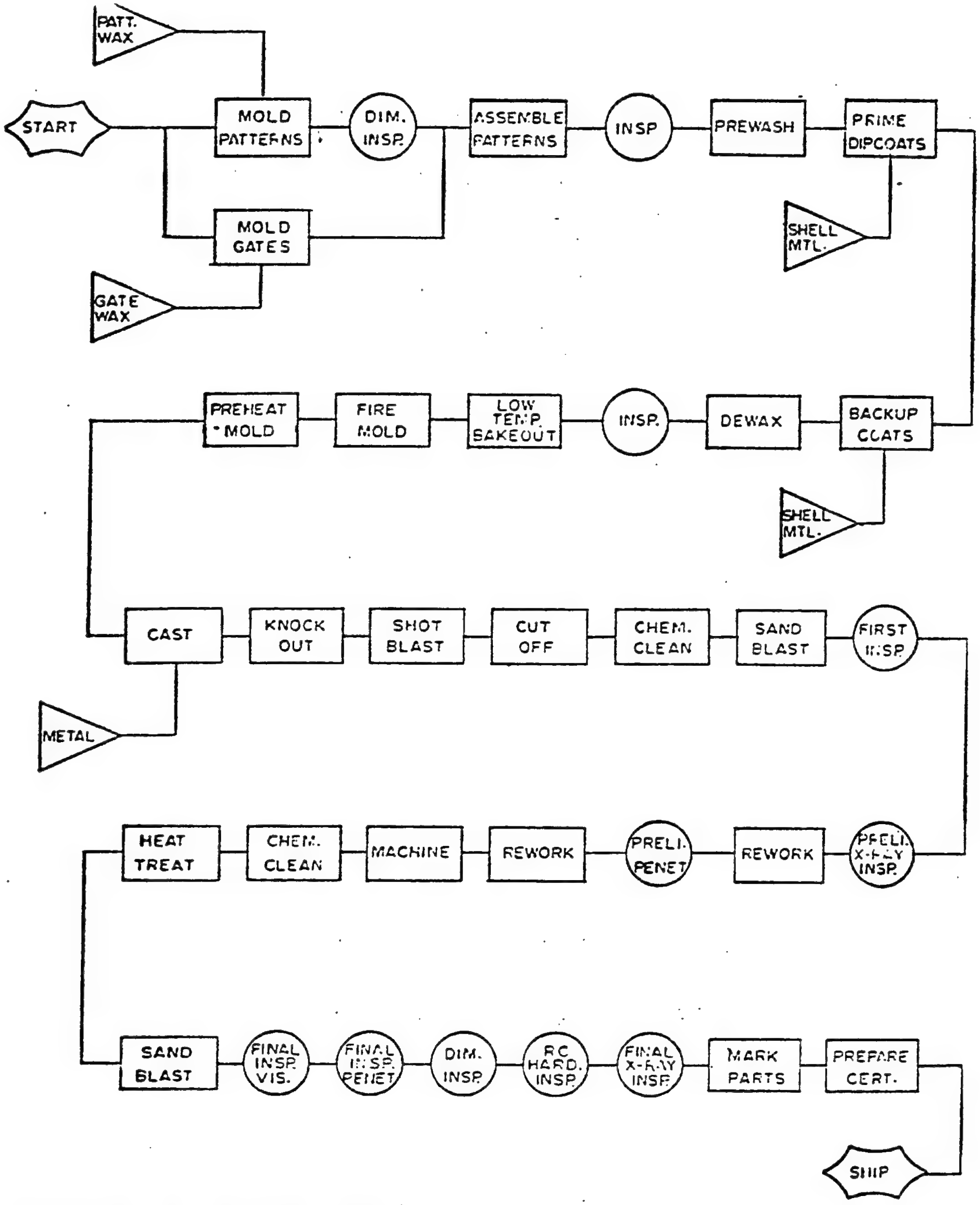
There are undoubtedly other similar tubular parts such as elbows, connectors, bosses, etc. which could reflect the same degree of improvement while simultaneously reducing cost. We have estimated savings of 10 to 50 percent on various type castings presently being used.

2. Non-destructive Testing - Consideration should be given to only grading a component to the level required to accomplish the task. This can have a remarkable effect on cost as reflected in the attached tabulation. The yield as well as the repair and rework cycles play a significant role in establishing the cost of the final product. In many instances, a part is established as requiring a specific NDT level. Frequently, changes in design and/or changes in tolerances can result in less severe NDT requirements and a lower production cost. Value engineering reviews of castings by suppliers and buyers would help reduce costs in this area.

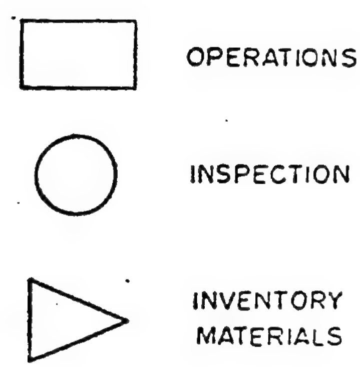
3. <u>Specifications vs. Drawings</u> - The most frequent approach to labeling the property requirements or NDT requirements is for the drawing to reference a specification and expect that this will result in the best product for the requirement. This is far from the actual real life situation.

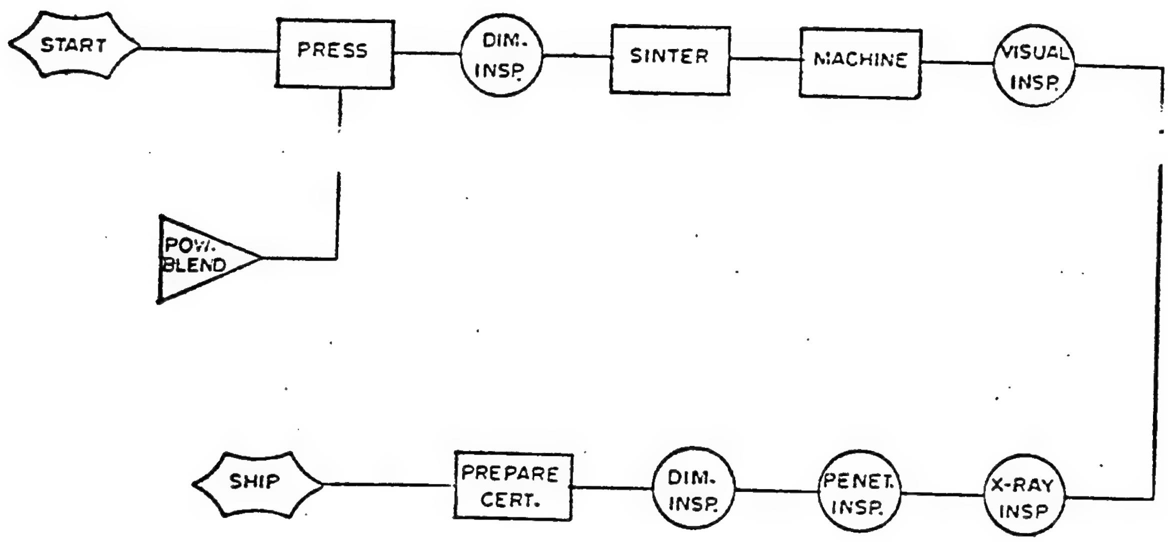
The drawing should call out the specific requirements for the part and only use the overall specification as a guideline. In this way, it is possible to become more specific on requirements and only produce to the required levels.

Another point that is frequently overlooked is the fact that just because a particular property or NDT level is required in one area of a casting this does not mean that the entire casting must be produced to this level.

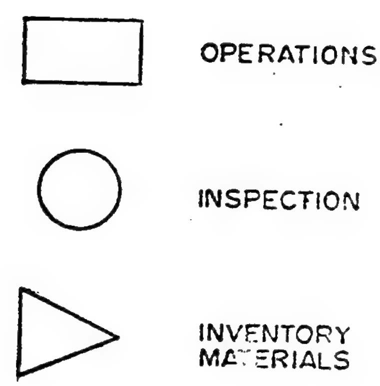


SCHEMATIC OF PRODUCT FLOW
INVESTMENT CAST TITANIUM
SEAL RING, TRANSFER TUBE





SCHEMATIC OF PRODUCT FLOW
POWDER METALLURGY TITANIUM
SEAL RING, TRANSFER TUBE



ESTIMATED COST CHANGE IN CASTINGS DUE TO GRADING

1. Standards based on the following:

   Per MIL-C-6021

   1A. Casting loss results in loss of aircraft or missile, etc.

   1B. Casting loss results in loss on major component, which might result in loss of aircraft or missile.

   2A. Castings with a safety margin of 200 percent or less.

   2B. Castings with a safety margin of 200 percent or greater where no stress analysis is required.

2. Steel castings are further classified by grade critical and non-critical areas between grades, grades A,B,C,D.

3. Titanium castings -- Pratt and Whitney Aircraft equivalent to TIS 340D.

   a. Assumption.

   Grade A = 1A
   Grade B = 1B
   Grade C = 2A
   Grade D = 2B

4. Steel castings.

   IA Grade A

   a. Simple castings only -- 60 percent yield.

   b. Normal castings -- 50 to 60 percent yield with no repair, 75 percent with repair (percentage parts rework 15 percent).

   c. Difficult castings -- not possible without major repair.

   IB Grade B

   a. Simple castings -- 70 percent yield.

   b. Normal castings -- 60 to 70 percent yield with no repair, 80 to 85 percent yield with repair (percentage parts rework 15 percent).

   d. Difficult castings with repair 75 percent yield (percentage parts rework 50 percent).

IIA Grade C

a. Simple castings -- 90 percent yield.

b. Normal castings -- 85 percent without repa[illegible] to 95 percent yield with repair (percentage rew[illegible] percent).

c. Diff[illegible] castings -- 85 percent yield w[illegible] repair (percentage rew[illegible]cent).

IIB Grade D

a. Simple castings -- 99 percent yield.

b. Normal castings -- 90 percent yield with no repair, 95 percent yield with repair (percentage rework 5 percent)

c. Difficult castings -- 95 percent yield with repair (percentage rework 30 percent).

5. Titanium castings Pratt and Whitney Aircraft standards.

Grade A

a. Simple castings -- 60 percent yield with no repair, 85 to 90 percent with repair.

b. Normal castings -- 70 percent yield with repair (percentage repair rework 100 percent).

c. Difficult castings -- not possible.

Grade B

a. Simple castings -- 70 percent with no repair, 90 to 95 percent with repair.

b. Normal castings -- 80 percent yield with repair (percentage repair rework 90 percent).

c. Difficult castings -- 70 percent yield with 100 percent repair (minimum of 2 cycles).

Grade C

a. Simple castings -- 85 percent with no repair

b. Normal castings -- 90 percent yield with 80 percent of parts requiring repair (1 to 2 cycles).

c. Difficult castings -- 75 percent yield with 100 percent repair (minimum of 2 cycles).

Grade D

a. Simple castings -- 90 to 95 percent yield with no repair.

b. Normal castings -- 60 percent yield with no repair, 90 percent with repair (percentage of rework 30 percent) (minimum 2 cycles).

c. Difficult castings -- 80 to 90 percent yield with repair, 100 percent of castings repaired (minimum 2 cycles).

<u>Note</u>: In steel or titanium, both repair costs and gate removal costs due to increased gating costs should about double as you move up one grade.

PART E

ROTATING ENGINE COMPONENTS
PANEL REPORT

I. INTRODUCTION

This report contains the results of the activities of the Rotating Engine Components Panel pursuant to fulfilling the objectives of the Air Force/Industry Manufacturing Cost Reduction Study Meeting held at Sagamore, New York, on 28 August - 1 September 1972.

Because of time constraints, it was decided to restrict ourselves to consideration of three basic components: forged blades, forged disks, and cast blades. Specific components selected, the ground rules or stipulations under which the analysis was to be performed, and panel member assignments were made as shown in Table E-I.

II. DISCUSSION

A detailed step by step operational cost analysis was performed on the entire spectrum of component manufacture, including all inspection operations, from procurement and melting of raw material to placing the product in finish stores by the engine manufacturer. Next, these detailed operations were subjected to analysis to identify functional costs. The results of the individual component functional analyses are shown in Appendix E-1.

A summary of the "component functional analyses" is shown in Table E-II. Rough part weights, finish part weights, and a part cost index are included to provide a frame of reference for identification of relative

TABLE E-I

PANEL STUDY ASSIGNMENTS

COMPONENT	STIPULATIONS: ENGINE SIZE	STIPULATIONS: ALLOY	STIPULATIONS: CONFIGURATION	STIPULATIONS: QUANTITY	BILLET OR RAW MAT'L PRODUCER	FORGER OR CASTER	ENGINE USER
Fan Blade	20,000 lb* class	Ti-6-4	Shrouded	1000 blade buy following 500th engine	Vaughn	Lake	Athey
Fan Blade	Same	Same	Unshrouded	Same	Vaughn	Lake	Stalker
Fan Disk	20,000 lb* class	Ti-6-4	Winged	20 disk buy following 500th engine	Vaughn	Coyne	Stalker
Fan Disk	Same	Ti-6-2-4-6	Same	Same	Vaughn	Coyne	Athey
Turbine Disk	20,000 lb* class	Inco 718	Winged	20 disk buy following 500th engine	Richmond	Coyne	Stalker
Turbine Disk	Same	Rene 95	Same	Same	Richmond	Coyne	Stalker
Turbine Disk	Same	Astroloy	Same	Same	Richmond	Coyne	Athey
Turbine Disk	Same	IN100	Same	Same	Wentzell	Athey	Athey
Turbine Blade	20,000 lb* class	Rene 80	Cored	2000 blade buy following 500th engine	Freeman	Freeman	Stalker
Turbine Blade	Same	B-1900+Hf	Solid	Same	Freeman	Freeman	Siegel
Turbine Blade Coatings	20,000 lb* class	Rene 80	Aluminide Coating	2000 blade buy following 500th engine			Stalker
Turbine Blade Coatings	Same	B-1900+Hf	Vapor Deposited Coatings	Same			Siegel

* + thrust

TABLE E-II

SUMMARY OF FUNCTION/COST ANALYSES

COMPONENT	ALLOY	ROUGH PART WT. #	FINISH PART WT. #	% of TOTAL COST						COST INDEX
				RAW MAT'L	MAT'L PROCESS	HEAT TREAT	MAT'L REMOVAL	SURFACE TREATMENT	INSPECT & TEST	
Fan Blade (w/ damper)	Ti-6-4	5.39	3.25	5	23	1	26	35	9	1.65
Fan Blade (w/o damper)	Ti-6-4	3.88	2.75	7	31	1	27	23	11	1.0
Fan Disk	Ti-6-4	256	103	8	16	2	51	6	17	25.0
Fan Disk	Ti-6-2-4-6	266	108	11	25	2	47	-	15	32.0
Turbine Disk	Inco 718	273	193	20	14	1	54	-	11	58.0
Turbine Disk	Rene 95	275	195	18	14	1	58	-	9	168.0
Turbine Disk	Astroloy	265	187	15	9	1	67	-	8	165.0
Turbine Disk	IN100	125	50	11	13	1	55	-	20	95.0
Turbine Blade (Solid)	Rene 80 Al Coat.			8	7	-	25	34	26	.3
Turbine Blade* (Hollow)	B-1900+Hf CoCrAlY coat.			4	16	-	36	18	13	.9

*13% of Cost is Scrap

costs. As a matter of interest for designers, during the course of the functional study it was revealed that a fan blade with a mid-span shroud costs 1.7 times more than a fan blade without the shroud, a winged disk costs 2 times more than a flat disk, and a cored or hollow turbine blade is 3 times the cost of a solid blade.

Having completed the functional analyses, the panel proceeded to review in detail those functions which contribute most to component cost, with a view toward evolving approaches for significant component acquisition cost reduction. In Table E-III the problem areas or "culprits" are identified, along with contribution to component cost and recommended approaches or programs for cost reduction are shown with priority indicated. Although some of the approaches listed are visionary, most offer real potential. Obviously, a great deal more "in depth" study is required to determine worth of the recommended approaches. Once this is accomplished, specific programs can be designed to bring about effective cost reduction.

The information in Tables E-II and E-III provides a reasonably firm basis for establishing the sources for high costs of rotating engine components. The data in Table E-II displays clearly the increases in costs resulting from more complex designs, higher strength, and higher temperature capability of the parts studied. A truism is reiterated by these data: high performance in turbine engines means higher costs.

The priorities shown in Table E-III reflect the consensus of the panel and it should be noted that in arriving at these priorities there was little or no disagreement among the panel members. The emphasis on

TABLE E-III

COST "CULPRITS"

COMPONENT	CULPRIT	PRESENT CONTRIBUTION (1)	RECOMMENDATION
1. All Disks (Ti & Ni)	Machining Costs	50-65%	Improved metal removal techniques
2. All Disks (Ti & Ni)	Low material yield	(2)	Isothermal forge, closer to net shape
3. All Disks (Ti & Ni)	Low material yield	(2)	Fabricated shapes
4. All Disks (Ti & Ni)	Inadequate sonic insp. technique	(3)	Improved sonic insp. techniques
5. Ni Disks	Forgeability	5%	ESR
6. All Disks	Redundant insp. and tests	3%	Eliminate redundant insp. & tests
7. All Parts	Scrap utilization	7%	Allow more revert
8. All Parts	Unknown effects of trace elements	Unknown	a. Define effects b. Improve analyses
9. Cast Cored Turb. Airfoils	Core shift,	10%	Stronger core & attachment improved access
10. Cast Turbine	High machining cost	28%	Cast closer to finish dimensions; Improve mental removal technique
11. Fan Blades (Shrouded)	High cost of mid-span shroud and hard facing	18%	Establish more economical hard facing/source
12. Powder Metal Ni Disks	High cost of powder extn. billet	15%	Increased billet length & diameter; Improved consol tion techniques
13. All Disks	Restricted die life	5%	Improvec forming technique

(1) Portion of component cost attributable to "culprit".
(2) Finished disks represent about 15% of total material input.
(3) Relates to requirement for sonic outline.

improving metal removal practice and producing closer net shapes is an obvious decision, in view of high machining costs and low material yield in finished parts, particularly disks. An interesting additional effect of these costs can be seen in recommendations 7 and 8 of Table E-III, dealing with scrap utilization and the effects of residual elements. These items were considered to be of significant technological importance, since scrap losses associated with superalloy turbine blade castings, particularly the hollow air foils, was the third major area of concern to the panel. Here the effects of design considerations (e.g., the location, size, and shape of cores and the means for retaining their position) was the topic of some discussion. More activity in the area of material/process/design interaction could be a fruitful source for cost reduction.

Serious concern was frequently expressed during the course of the study conducted by the Rotating Engine Components panel over pressures and constraints imposed by the Government, which were felt to create and perpetuate high cost situations. Specific examples mentioned included the following:

The "it shall not fail" syndrome

Procurement practices relating to the acquisition of military engines

Unrealistic engine life and performance requirements with unrelenting pressure to hold down costs

Policies relating to foreign suppliers of basic raw materials such as titanium sponge and chromium.

It is strongly recommended that future efforts on the part of the Air Force and industry to bring about significant cost reduction include thoughtful and serious consideration of these and other like items.

III. CONCLUSIONS

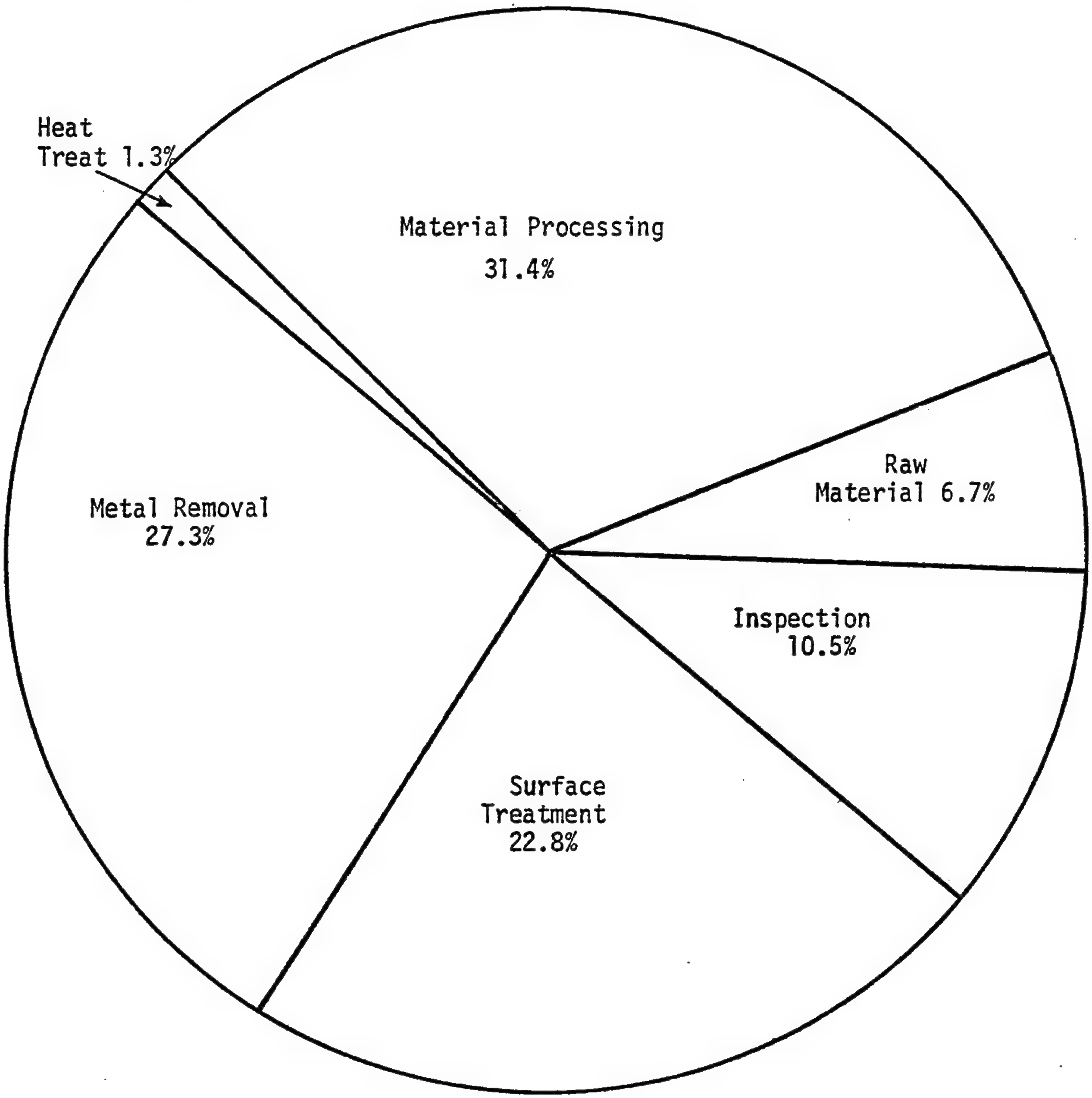
It is felt that this study effort has provided a solid foundation or point of departure for future independent and/or cooperative cost reduction action of Government and Industry. During the course of the study, ideas, concerns, and awareness of problems were brought about which are bound to spawn cost reduction consciousness and action which will pay dividends. It is very important that this excellent start be followed-up by a continuing and concerted effort on the part of both Government and Industry.

IV. APPENDIX E-1

FAN BLADE
(UNSHROUDED)

Ti-6-4

FAN BLADE - No Damper
Ti-6Al-4V



SUMMARY FUNCTION ANALYSIS

COMPONENT Fan Blade (No Damper)

MATERIAL Ti 6Al-4V

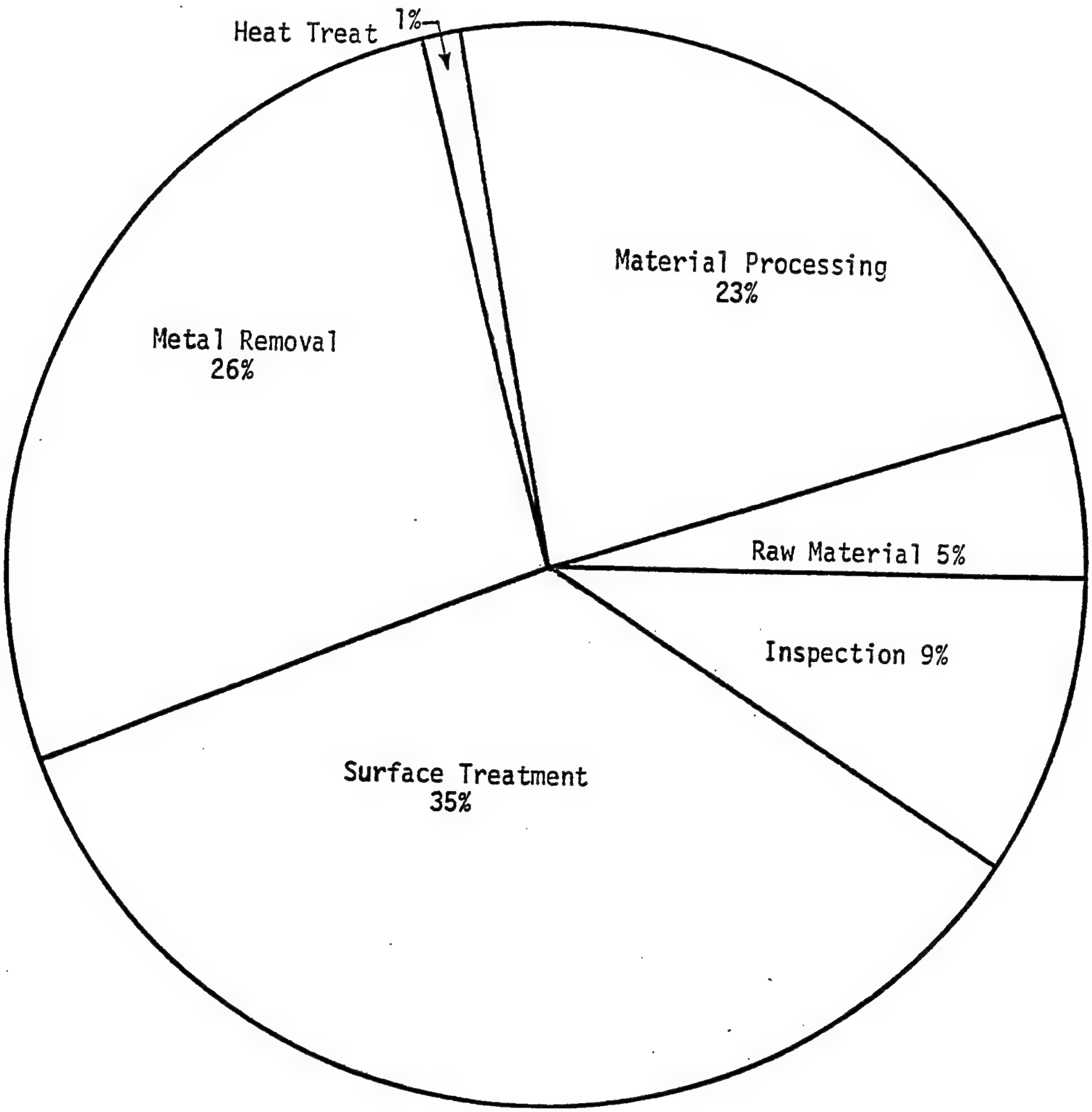
50 Blades = 194# Starting Bar

FUNCTION	% Total Cost			Costs ($ Per Blade)		
	Supplier	Forger	Total	Supplier	Forger	Total
Raw Material	6.71	-	6.71	5.00	-	5.00
Material Processing	5.93	25.49	31.42	4.42	19.00	23.42
-- Melting	(1.82)	-		(1.36)	-	
-- Casting	-	-		-	-	
-- Consolidation	(1.31)	-		(0.98)	-	
-- Forging	(2.79)	(25.49)		(2.08)	(19.00)	
Heat Treatment	-	1.34	1.34	-	1.00	1.00
-- Mechanical Properties	-	-		-	-	
-- Stress Relief	-	(1.34)		-	(1.00)	
Material Removal	8.48	18.78	27.26	6.32	14.00	20.32
-- Mechanical	(8.48)	(18.78)		(6.32)	(14.00)	
- Chemical	-	-		-	-	
Surface Treatment	-	22.81	22.81	-	17.00	17.00
- Mechanical	-	(16.10)		-	(12.00)	
- Chemical (Coat Root)	-	(6.71)		-	(5.00)	
Inspection	2.41	8.05	10.46	1.80	6.00	7.80
-Dimensional	-	(6.04)		-	(4.50)	
-Quality	(2.41)	(2.01)		(1.80)	(1.50)	
TOTAL	23.53	76.47	100.00	17.54	57.00	74.54

FAN BLADE
(Shrouded)
Ti-6-4

FAN BLADE - Midspan Damper
Ti-6Al-4V

(Cost is 156% of Blade Without Damper)



SUMMARY FUNCTION ANALYSIS

COMPONENT Fan Blade (Mid-Span Damper)

MATERIAL Ti 6Al-4V

50 Blades = 269.5# Starting Bar

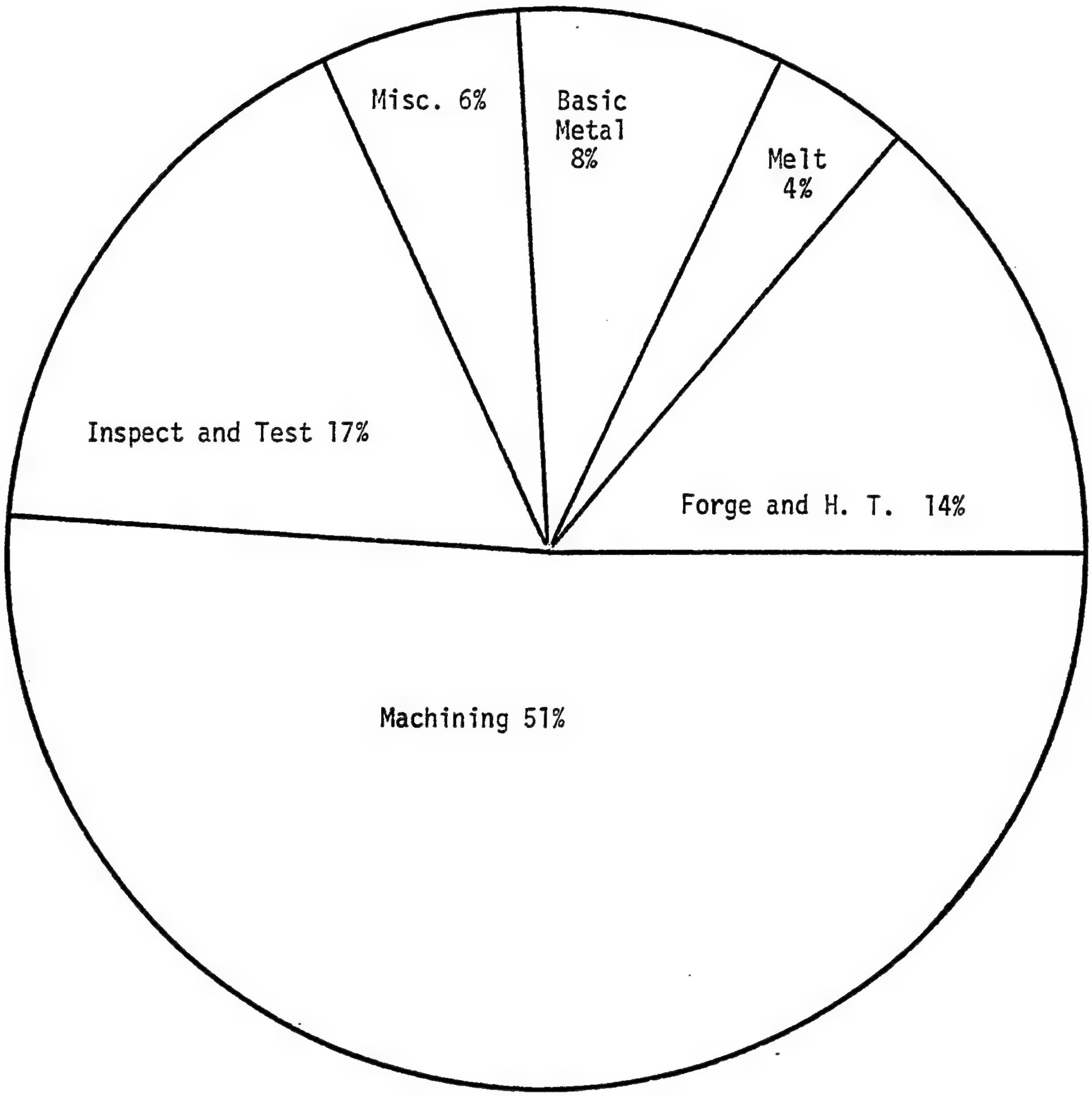
FUNCTION	% Total Cost			Cost (# Per Blade)		
	Supplier	Forger	Total	Supplier	Forger	Total
Raw Material	5.59	-	5.59	6.95	-	6.95
Material Processing	4.94	18.49	23.42	6.14	23.00	29.14
- Melting	(1.52)	-		(1.89)	-	
- Casting	-	-		-	-	
- Consolidation	(1.09)	-		(1.35)	-	
- Forging	(2.34)	(18.49)		(2.90)	(23.00)	
Heat Treatment	-	0.80	0.80	-	1.00	1.00
- Mechanical Properties	-	-		-	-	
- Stress Relief	-	(0.80)		-	(1.00)	
Material Removal	7.07	19.29	26.36	8.79	24.00	32.79
- Mechanical	(7.07)	(19.29)		(8.79)	(24.00)	
- Chemical	-	-		-	-	
Surface Treatment	-	34.56	34.56	-	43.00	43.00
- Mechanical	-	(16.08)		-	(20.00)	
- Chemical (Hardface Span & Coat Root)	-	(18.49)		-	(23.00)	
Inspection	2.03	7.23	9.27	2.52	9.00	11.52
- Dimensional	-	(5.42)		-	(6.75)	
- Quality	(2.03)	(1.81)		(2.52)	(2.25)	
TOTAL	19.62	80.38	100.00	24.40	100.00	124.40

FAN DISK

(Integral Arm)

Ti-6-4

FAN DISK
Ti-6-4



OPERATION AND FUNCTION ANALYSES

COMPONENT: Fan Disk   Material: Ti-6-4

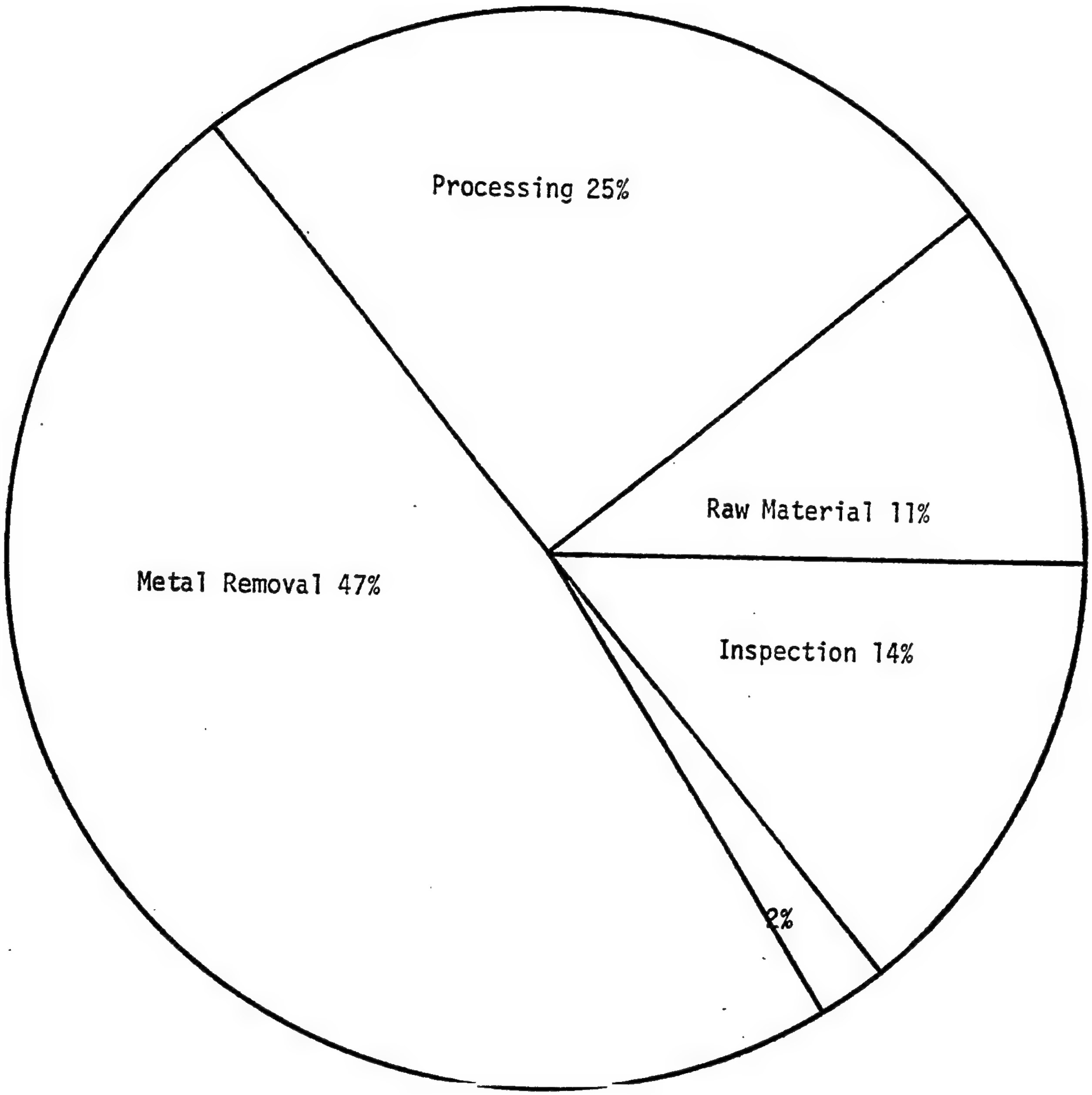
OPERATION		%	$
Basic Sponge & Master Alloy		8	148
Melting, Pressing, Cond & HT		10	185
Forging & HT		9	167
Machining - Rough		15	278
Forging Inspection & Test		4	74
Machine-Finish Turn		17	315
Bench, Mill & Drill		18	333
Inspect & Zyglo		13	241
Shot Peen, Wash, Etc.		6	111
		100	1852
FUNCTION			
Basic Metal		8	148
Melting		4	74
Forging & HT		14	259
Machining		51	944
Inspect & Test		17	316
Misc.		6	111
		100	1852

FAN DISK

(Integral Arm)

Ti-6-2-4-6

FAN DISK
Ti-6-2-4-6



OPERATION ANALYSIS (MELTER)

266#

COMPONENT: Fan Disk

Material: Ti-6-2-4-6

OPERATION		% SP	$ Per Disk
Sponge & Master Alloy		42.4	449
Raw Material Insp.		1.5	16
Blending, Compacting, Welding		5.4	57
Melting		9.8	104
Chemical Analysis		.8	8
Forging		8.8	93
Conditioning		4.7	50
Turning		13.2	140
Mech. Testing		2.5	26
Sonic Testing		2.0	21
Cutting		4.9	52
Micro/Macro Testing		3.2	34
Shipping		.8	8
		100	1059

OPERATION AND FUNCTION ANALYSES (FORGER)

COMPONENT: Fan Disk

MATERIAL: Ti-6-2-4-6 266# Ship 108#

OPERATION	% SP	$ Per Disk
Procure Material	52	1059
Scrap Test	1	20
Forge & Forge S.U.	8	163
Prep for Force		
Pre HT Machine	21	428
HT	4	81
Machine for Sonic	9	183
Sonic & Zyglo	1	20
Integral Test	4	81
	100	2035

FUNCTION

	%	$ Per Disk
Raw Material	2	1059
Heat Prep	9	183
Heat Treat	4	81
Material Prep	29	590
Input	6	122
	100	2035

OPERATION ANALYSIS (USER)

COMPONENT: Fan Disk MATERIAL: Ti-6-2-4-6

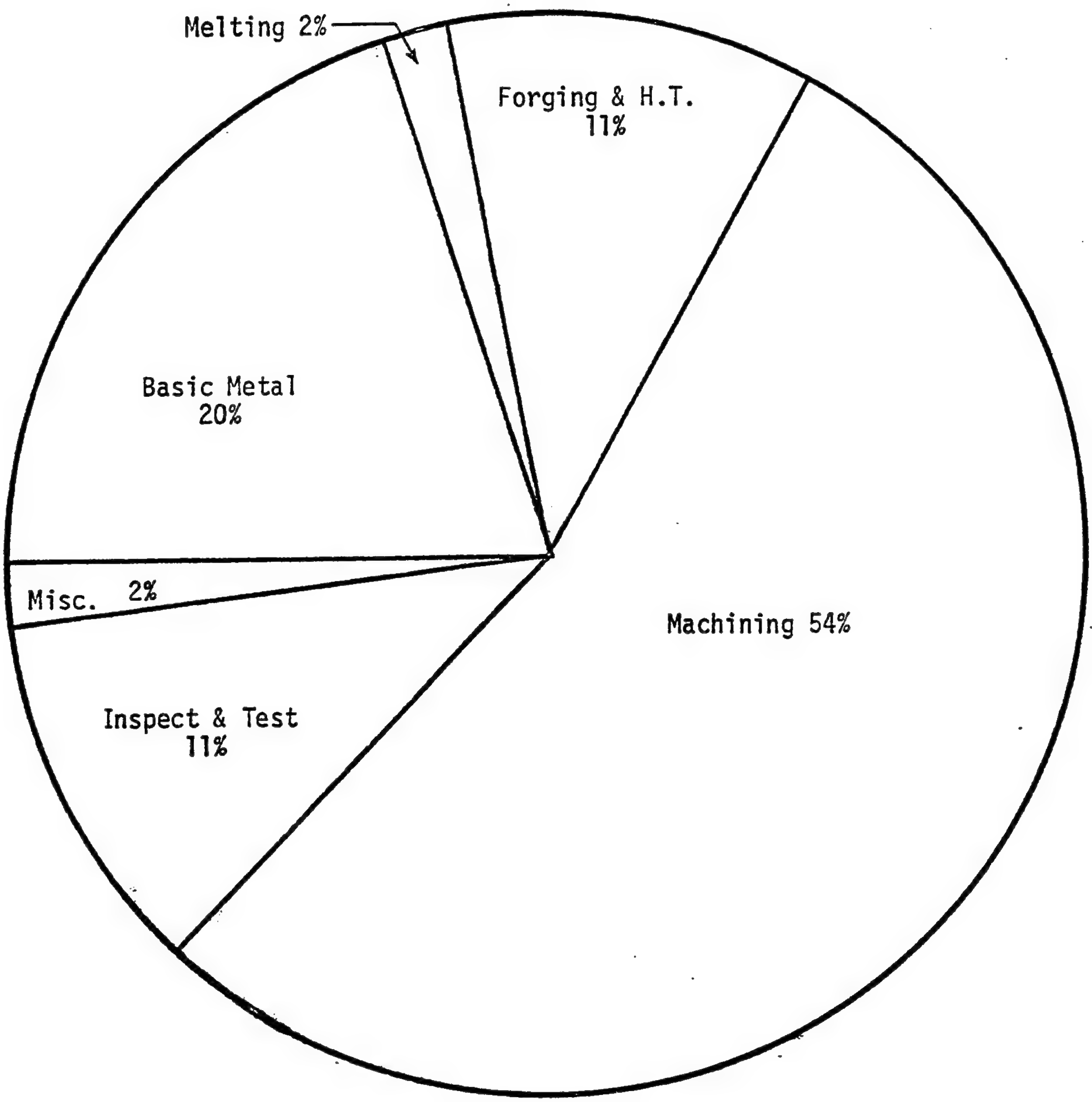
OPERATION		%	$ Per Disk
Forging		49.8	2035
Machine Bore		2.5	102
Machine Front		4.2	171
Machine Rear		5.6	228
Drill Bolt Holes		9.3	379
Machine Blade Slots		5.2	212
Machine Brg Attachment		6.0	245
Finish		7.2	294
Inspect		10.2	416
		100	4082

TURBINE DISK

(Integral Arm)

Inco 718

TURBINE DISK
INCO 718



OPERATION AND FUNCTION ANALYSES

COMPONENT: Turbine Disk

MATERIAL: Inco 718

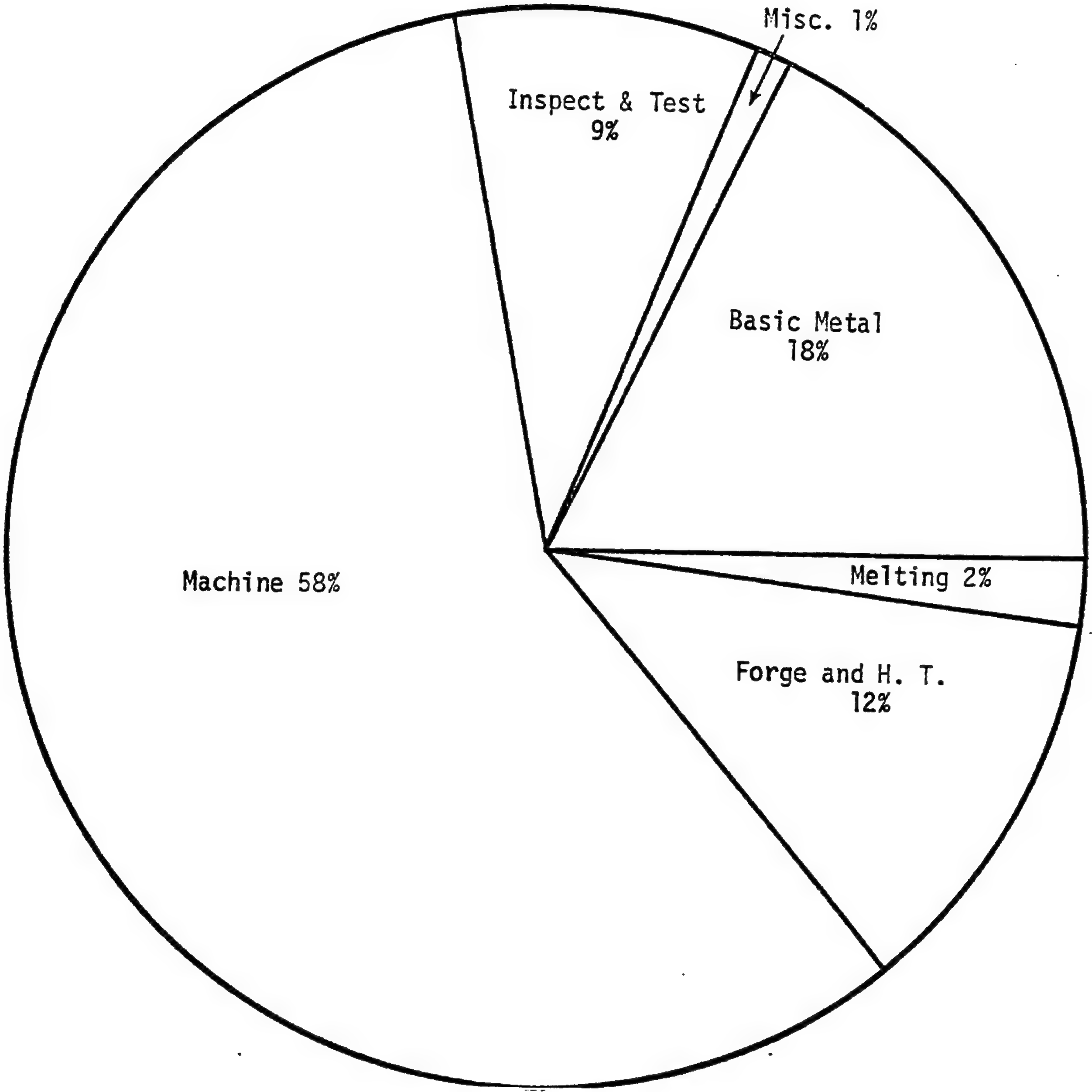
OPERATION		%	$ Per Disk
Master Metal & Revert		20	1622
Melting, Pressing, Comp & HT		4	324
Forge & HT		10	811
Machine - Rough		15	1217
Inspect & Test		7	568
Machine - Finish Turn		21	1703
Broach, Mill & Drill		17	1379
Inspect & Zyglo		4	324
Shot Peen, Wash, Etc.		2	162
		100	8110
	FUNCTION		
Basic Metal		20	1622
Melting		2	162
Forging & HT		11	892
Machining		54	4380
Inspect & Test		11	892
Misc.		2	162
		100	8110

TURBINE DISK

(Integral Arm)

Rene 95

TURBINE DISK
R 95



OPERATION AND FUNCTION ANALYSES

COMPONENT: Turbine Disk | MATERIAL: Rene 95

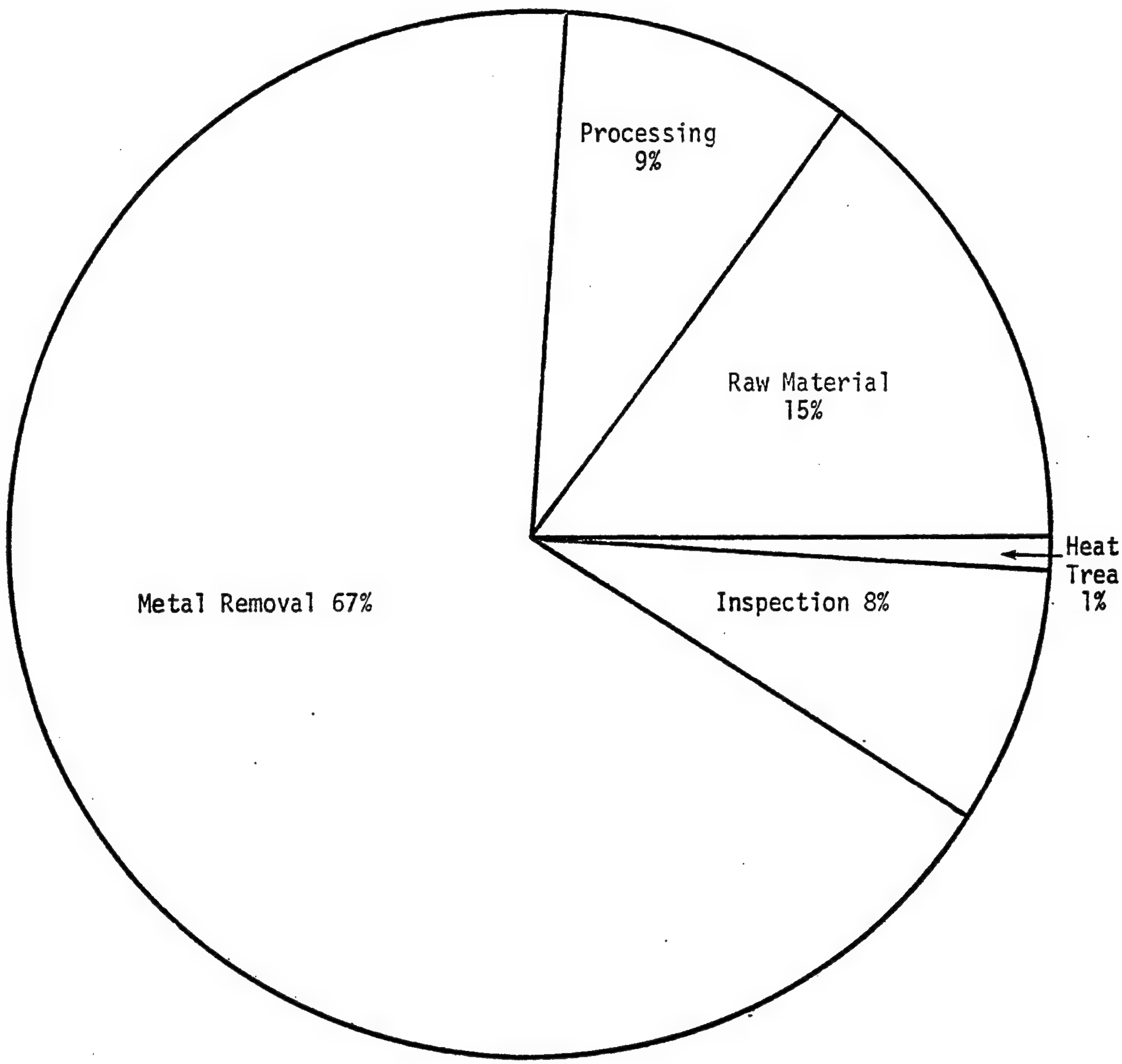
OPERATION		%	$ Per Disk
Master Metal & Revert		18	3201
Melting, Press, Cond. & HT		3	533
Forge & HT		11	1956
Machining - Rough		30	5335
Inspect & Test		6	1067
Machine - Finish Turn		16	2845
Broach, Mill & Drill		12	2134
Inspect		3	533
Shot Peen, Wash, Etc.		1	178
		100	17783
	FUNCTION		
Basic Metal		18	3201
Melting		2	356
Forge & HT		12	2134
Machining		58	10314
Inspect & Test		9	1600
Misc.		1	178
		100	17783

TURBINE DISK

(Integral Arm)

Astroloy

TURBINE DISK
Astroloy



OPERATION AND FUNCTION ANALYSES (MELTER)

COMPONENT: Turbine Disc

MATERIAL: Astroloy 11-3/8" Turned Ingot

OPERATION	MACHINE/TECHNIQUE	%	$ Per Disk
Raw Material	Virgin & Purchased Scrap & Revert	84.8	3132
Vac Ind Melt	VIM (9" Electrode)	3.7	137
Vac Arc Remelt	VAR (12-3/4" ingot)	2.6	96
Condition & Machining	Midwest Grind Electrode Turn Ingot	8.4	310
Other Conversion	Annealing, Cutting, Internal Shipping	0.2	7
Testing	Macro/Micro	0.3	11
		100.0	3693
FUNCTION			
Raw Material		84.8	3132
Material Proc.		6.3	233
Heat Treatment		0.2	7
Material Removal		8.4	310
Inspection		0.3	11
		100.0	3693

OPERATION AND FUNCTION ANALYSES (FORGER)

COMPONENT: Turbine Disk

MATERIAL: Astroloy 11-3/8" Ingot 890#

Ship Wt. 265#

OPERATION	%	$ Per Disk
Procure Raw Material	31.5	3696
Accept Test	1.2	146
Forge & Forge Set-up	3.5	410
Prep & In-process Cond, In-Process Insp, Insulation & Lubrication	8.1	950
Heat Treat	2.3	275
Machine for HT	28.1	3300
Sonic & Zyglo	3.3	390
Machine for Zyglo	14.2	1670
Other	5.3	625
Integral Testing	2.5	290
	100.0	11752

FUNCTION	%
Raw Material	31.5
Material Processing	11.6
Heat Treat	2.3
Mat'l Removal	47.6
Inspection	7.0
	100.0

OPERATION ANALYSIS (USER)

COMPONENT: Turbine Disk

MATERIAL: Astroloy

OPERATION		%	$ Per Disk
Identify Forging		.1	13
Spin Test Inspect		3.0	280
Machine Faces		13.7	1260
Drill Cooling Holes		7.0	645
Machine Flanges		12.7	1170
Drill Bolt Holes, Machine Scallops		6.1	560
Machine Blade Slots		51.5	4730
Finish and Balance		2.9	266
Spin Test Inspect		.8	166
Barrel Finish, Mark		1.1	98
		100.0	9188

SUMMARY OPERATION ANALYSIS

COMPONENT: Turbine Disk

Material: Astroloy

	OPERATION		%	$ Per Disk
MELTER	Raw Material		15.0	3132
	Vac. Ind. Melt		.7	137
	Vac. Arc. Melt		.5	96
	Cond. & Machining		1.5	310
	Other Conversion			7
	Testing		.1	11
FORGER	Acceptance Testing		.7	146
	Forge & Forge Set-up		2.0	410
	Process		4.5	950
	Machine for Heat Treat		15.8	3300
	Heat Treat		1.3	275
	Sonic & Zyglo		1.8	390
	Machine for Zyglo		8.0	1670
	Other		3.0	625
	Integral Testing		1.3	290
USER	Identification		.1	13
	Inspect - Spin Test		1.3	280
	Machine Faces		6.0	1260
	Drill Cooling Holes		3.1	645
	Machine Flanges		5.6	1170
	Drill Bolt Holes & Scalg.		2.6	560
	Machine Blade Slots		22.6	4730
	Finish and Balance		1.3	266
	Spin Test Inspect		.8	166
	Barrel Finish & Mark		.5	98
		TOTAL		[illegible]

SUMMARY FUNCTION ANALYSIS

COMPONENT: Turbine Disk

MATERIAL: Astroloy Ingot

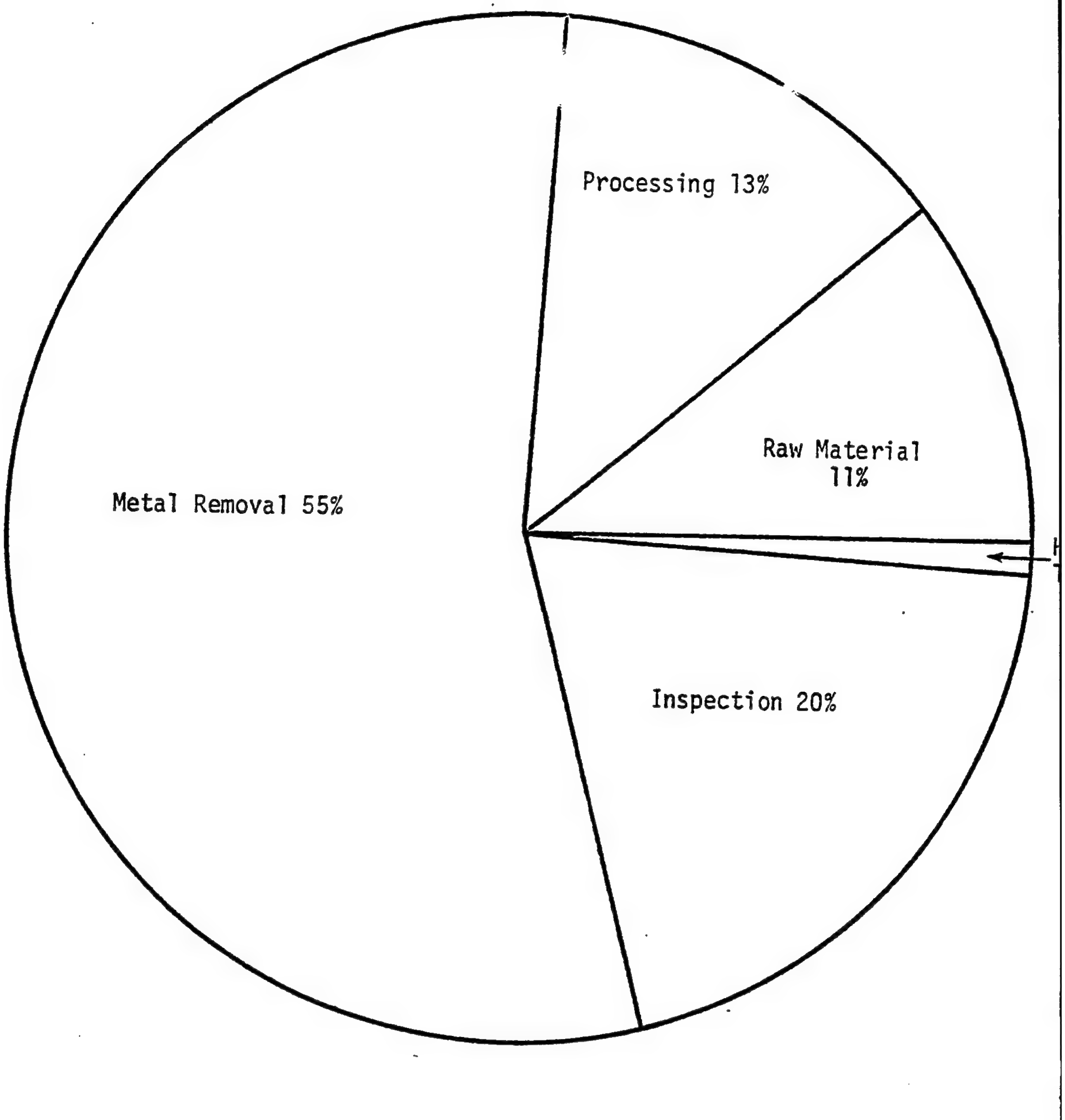
FUNCTION		% Total Cost	$ Per Disk
Raw Material			
Raw Material Processing		14.95	3132
(Double Melting)		1.1	233
Raw Material Processing			
(Conversion)		.03	7
Raw Mat'l Metal Removal			
Raw Mat'l Inspection		1.5	310
		.05	11
Forger Processing			
Forger Heat Treat		7.	1475
Forger Metal Removal		1.4	298
Forger Inspection		25.7	5389
		4.3	896
User Processing			
User Metal Removal		.5	111
User Inspection		39.9	8365
		3.4	712
	TOTAL	99.83	20939

TURBINE DISK

(Integral Arm)

IN100

TURBINE DISK
IN-100



FUNCTION ANALYSIS

COMPONENT: Turbine Disk

MATERIAL: IN100

FUNCTION		% Total Cost	$ Per Disk
Raw Material		10.7	1368
Raw Material Processing			
Melting		3.1	391
Consolidation and Forging		5.7	730
Raw Material Removal		1.7	220
Raw Material Inspection		1.4	173
Disk Forging		3.4	428
Disk Processing		.7	95
Disk Heat Treatment		.7	89
Disk Material Removal		53.1	6791
Disk Inspection		19.4	2480
	Total	99.9	12765

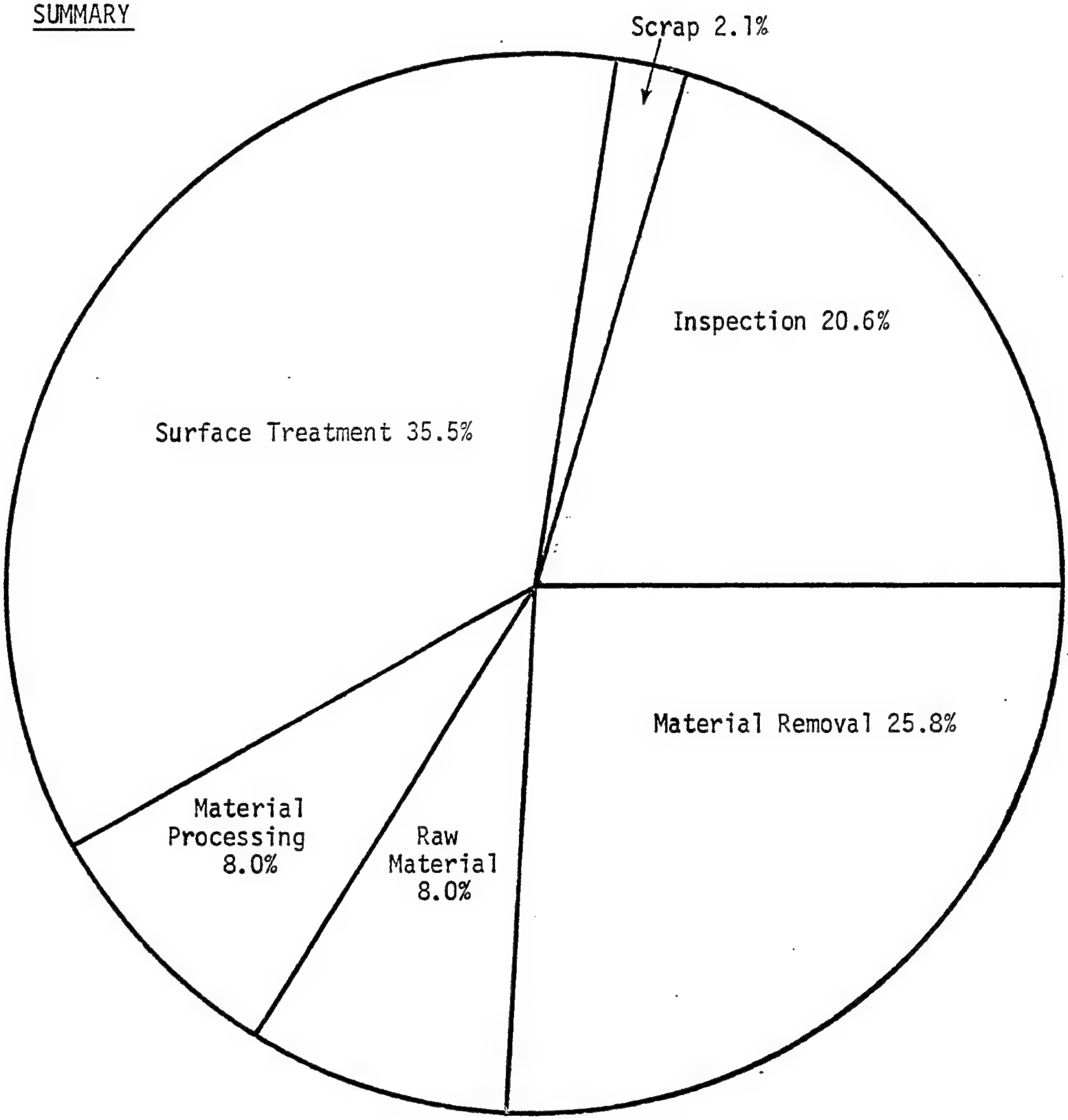
TURBINE BLADE

(Solid)

RENE 80

TURBINE BLADE - Uncooled
Rene 80/Aluminide Coating/Machining

SUMMARY



OPERATION AND FUNCTION ANALYSIS (CASTER)

COMPONENT: Turbine Blade - Uncooled MATERIAL:Rene 80 Casting

OPERATION		%	$
Alloy		45.0	6.75
Wax		8.8	1.32
Shell		2.9	.43
Casting		5.2	.78
Rough Visual		0.3	.05
Cleaning		2.3	.35
Sprue/Grind		6.9	1.08
First Inspect		0.3	.05
Finishing		4.9	.74
Final Visual		0.5	.08
Gauging		3.6	.54
Zyglo		3.8	.57
Final X-ray		3.5	.53
Ship		0.5	.08
Scrap		8.2	1.23
Insp.		1.7	.25
Machine		1.6	.24
FUNCTION			
Raw Material		45.0	6.75
Metal Processing		17.4	2.61
Material Removal		8.5	1.28
Surface Treatment		7.[illegible]	1.08
Inspection		13.7	2.06

FUNCTION ANALYSIS

COMPONENT: Turbine Blade - Uncooled　　　　MATERIAL: Rene 80 - Remelt Stock

FUNCTION		% Total Cost	$ Cost
Raw Material		69	4.65
Processing		31	2.10

OPERATION AND FUNCTION ANALYSIS (USER)

COMPONENT: Turbine Blade - Uncooled MATERIAL: Rene 80/Aluminide Coating/Machining

OPERATION		% Total Cost	$
Raw Material (Casting)		25.7	15.00
Fixture Blade		7.8	4.55
Machine		15.8	9.22
Coating		9.5	5.55
Shot Peen, Tumble		8.0	4.67
Polish		7.6	4.44
Inspection		17.1	9.98
Cleaning		8.5	4.96
FUNCTION			
Raw Material (Casting)		25.7	15.00
Metal Removal		23.6	13.77
Surface Treatment		33.6	19.61
Inspection		17.1	9.98
		100.0	5837

FUNCTION SUMMARY ANALYSIS

COMPONENT: Turbine Blade - Uncooled MATERIAL: Rene 80/Aluminide Coating/ Machining

FUNCTION		% Total Cost	$ Cost
Raw Material		8.0	4.65
Material Processing		8.0	4.65
Material Removal		25.8	15.00
Inspection		20.6	12.02
Scrap		2.1	1.23
Surface Treatment		35.5	20.72
		58.37	

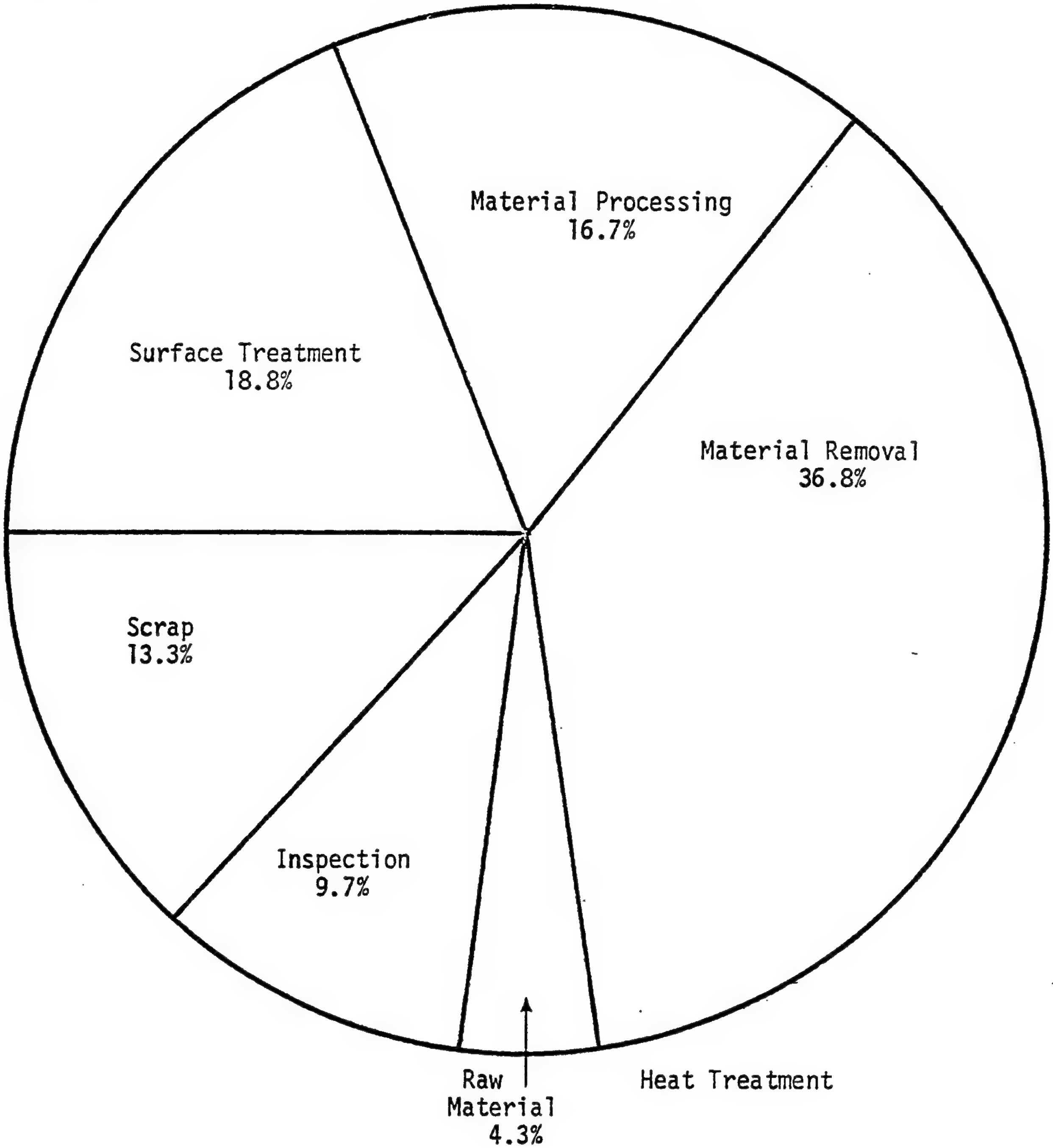
TURBINE BLADE

(Cooled)

B-1900+Hf

TURBINE BLADE - Cooled
B-1900+Hf/CoCrAlY Coated/Machined

SUMMARY



FUNCTION ANALYSIS

COMPONENT: Turbine Blade - Cooled MATERIAL: B-1900+Hf - Remelt Stock

FUNCTION		% Total Cost	$
Raw Material		69	5.05
Processing		31	2.25

OPERATION ANALYSIS (CASTER)

COMPONENT: Turbine Blade - Cooled MATERIAL: B-1900+Hf - Casting

OPERATION		%	$
Alloy		14.6	7.30
Wax		5.4	2.70
Shell		1.2	.60
Casting		2.5	1.25
Rough Visual		0.3	.15
Cleaning		1.2	.60
Rough Wall		0.5	.25
Sprue Grind		1.2	.60
Core Removal		3.8	1.90
Rough X-ray		0.8	.40
First Inspection		0.4	.20
Finishing		4.1	2.05
Final Visual		0.5	.25
T. Cycle & Zyglo		2.2	1.10
Final Wall & Gauge		1.2	.60
Final X-ray		5.5	2.75
Ship		0.5	.25
Scrap		30.3	15.15
Preformed Core		16.3	8.15
Inspect		4.2	2.10
Machine		4.2	2.10
			50.00

FUNCTION ANALYSIS (CASTER)

CONPONENT: Turbine Blade - Cooled MATERIAL: B-1900+Hf - Casting

FUNCTION		% Total Cost	$ Cost
Raw Material		14.6	7.30
Material Processing		33.6	16.80
Metal Removal		1.0	.50
Inspection		15.4	7.70
Surface Treatment		5.1	2.55
Scrap		30.3	15.15
			50.00

OPERATION AND FUNCTION ANALYSIS (USER)

COMPONENT: Turbine Blade - Cooled MATERIAL: B-1900+Hf/CoCrAlY Coating/Machining

OPERATION		%	$
Raw Material (Casting)		29.4	50.00
Fixture		9.2	15.60
Machine		36.3	61.70
Coat & Shot Peen		18.6	31.60
Heat Treat		.5	.80
Finish		2.1	3.60
Inspection		3.7	6.30
FUNCTION			
Raw Material (Casting)		29.4	50.00
Metal Removal		45.6	77.50
Surface Treatment		20.8	35.40
Heat Treatment		0.5	.80
Inspection		3.7	6.30
			170.00

SUMMARY FUNCTION ANALYSIS

COMPONENT: Turbine Blade - Cooled

MATERIAL: Coating/Machined B-1900+Hf/CoCrAlY

FUNCTION		% Total Cost	$
Raw Material		4.3	7.30
Material Processing		16.7	28.40
Material Removal		36.8	62.60
Heat Treatment		0.4	.70
Inspection		9.7	16.50
Scrap		13.3	22.60
Surface Treatment		18.8	32.00
			170.00

PART F - APPENDIX

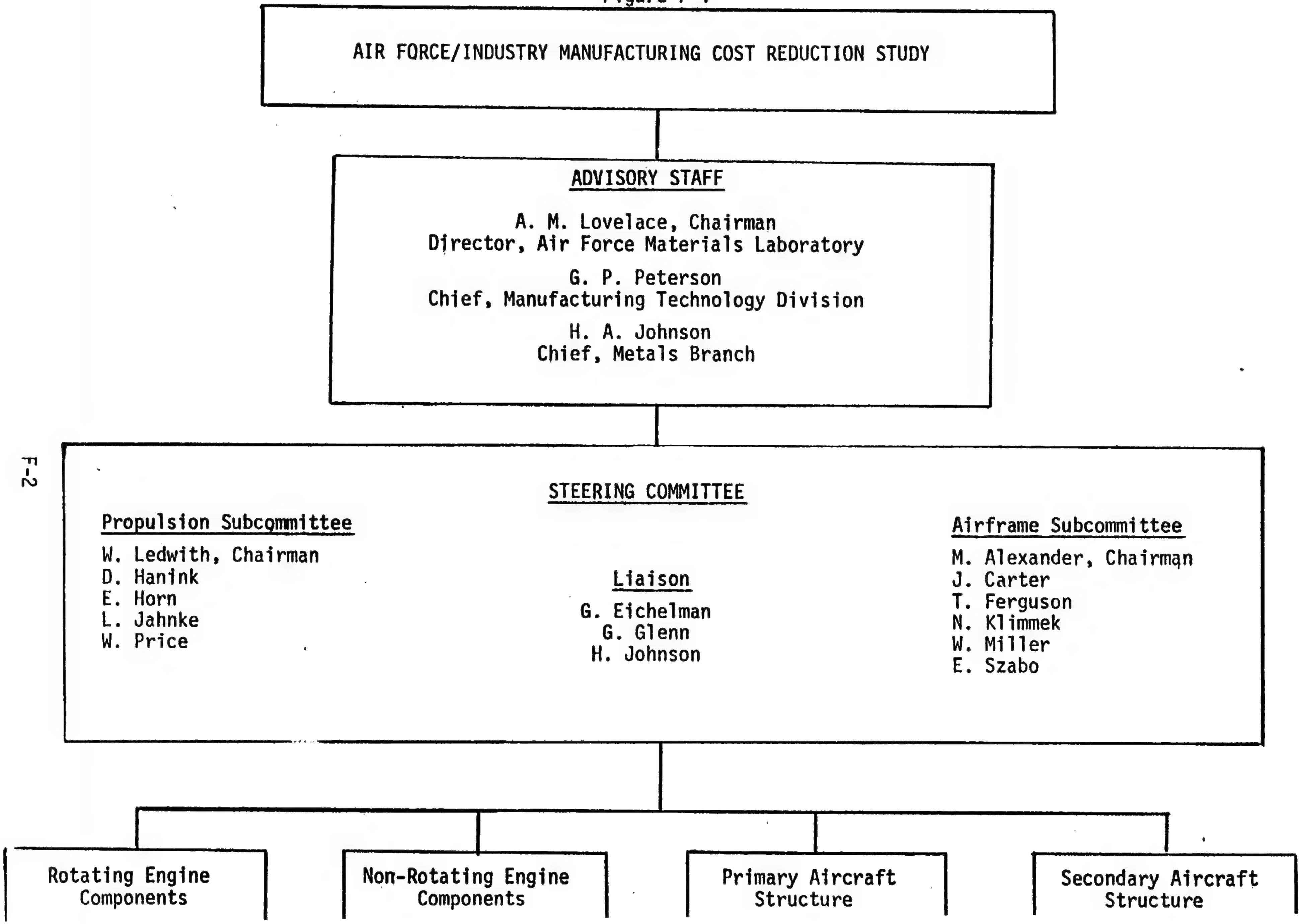
I. CONFERENCE ORGANIZATION

Planning for the Air Force/Industry Manufacturing Cost Reduction Study was initiated by the Air Force during June 1972. The planning and organizational effort was devoted primarily to the establishment of technical objectives which impacted directly upon the expressed Air Force interest in reducing manufacturing cost of aircraft structure and propulsion components. A series of planning meetings was convened with representatives of the Air Force and industry providing contributions pertaining to conference organization, format, modus operandi, data input and anticipated results.

The conference was held at Sagamore, New York during the dates of 28 August through 1 September 1972 with sixty-eight participants, representing more than twenty-five industrial firms and various Air Force organizations in attendance. The organizational structure for the Study is shown in Figure F-1. The Management of the Air Force Materials Laboratory provided the advisory inputs and guidance concerning study objectives and reporting requirements. The Steering Committee was divided into two Subcommittees, relating to the propulsion and structure working panels. The four working panels were chaired by industry members selected by reason of their association with the varying manufacturing activities within their specialty fields.

Several coordination meetings involving both Air Force and industry

Figure F-1


AIR FORCE/INDUSTRY MANUFACTURING COST REDUCTION STUDY
ADVISORY STAFF
A. M. Lovelace, Chairman
Director, Air Force Materials Laboratory
G. P. Peterson
Chief, Manufacturing Technology Division
H. A. Johnson
Chief, Metals Branch
STEERING COMMITTEE
Propulsion Subcommittee
W. Ledwith, Chairman
D. Hanink
E. Horn
L. Jahnke
W. Price
Liaison
G. Eichelman
G. Glenn
H. Johnson
Airframe Subcommittee
M. Alexander, Chairman
J. Carter
T. Ferguson
N. Klimmek
W. Miller
E. Szabo
Rotating Engine Components
Non-Rotating Engine Components
Primary Aircraft Structure
Secondary Aircraft Structure

Panel members were convened to discuss overall conference goals and to identify technical organization efforts and data requirements pertaining to the individual panels. A meeting of the Steering Committee and Air Force conference management personnel was held at the Air Force Materials Laboratory on 15 August 1972 to re-examine the role of the Steering Committee in light of Air Force goals. During these several coordination meetings, the Air Force outlined and summarized objectives for the Conference as shown in the following statements:

1. Quantitatively and qualitatively define cost of major airframe/aeropropulsion structural components (step-by-step).

2. Based on (1), determine best approaches for significant end item acquisition cost reduction, while maintaining present reliability and performance.

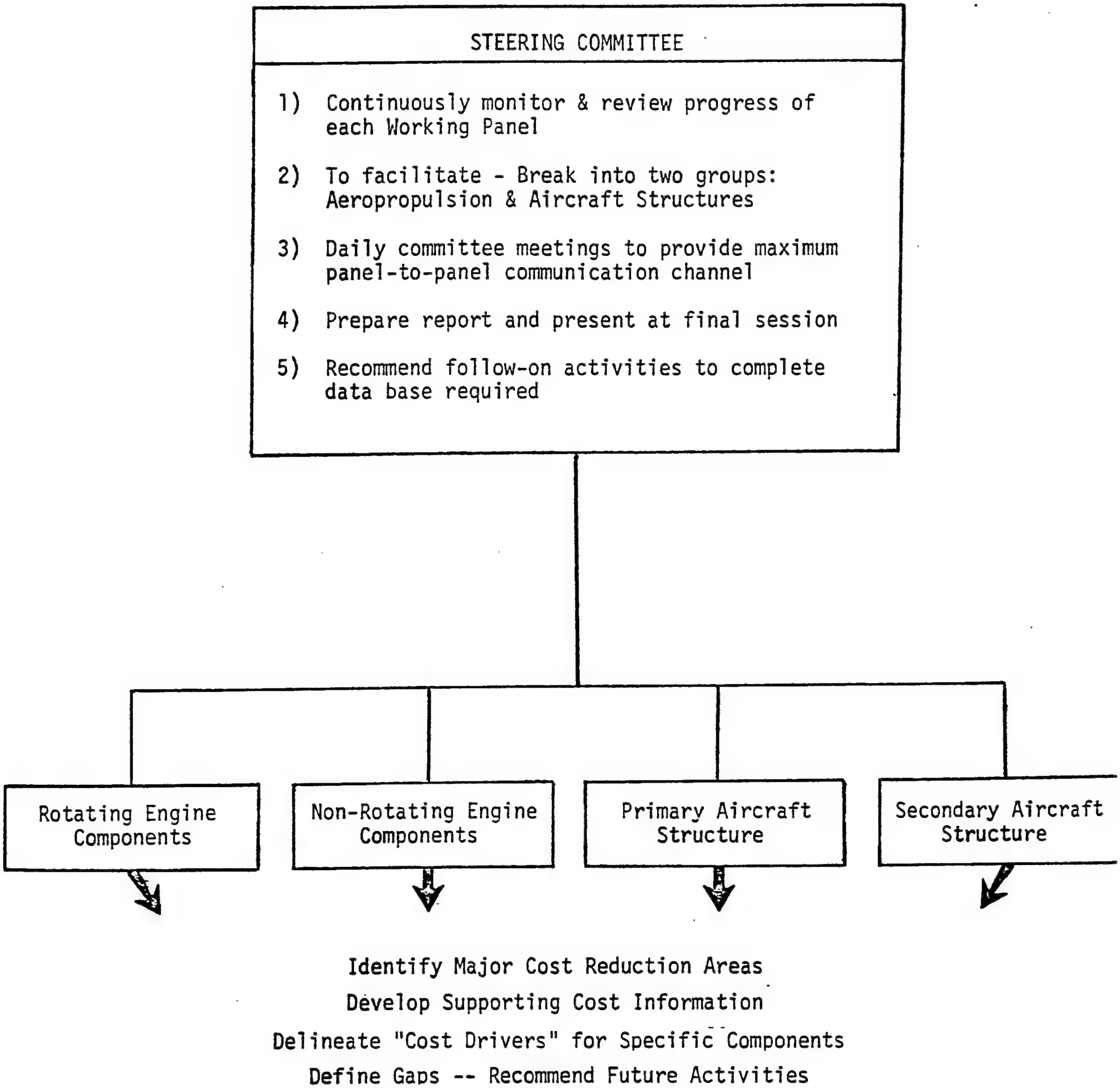
3. Define specific activities to demonstrate cost saving approaches.

With the overriding conference theme of manufacturing cost reduction studies for airframe and propulsion hardware in mind, the four panels met in separate sessions to select topical study areas and to evaluate the validity of available manufacturing-cost information. These meetings were held in collaboration with the Air Force panel liaison members at selective locations and convenient dates to the entire panel membership. These meetings served to assist in the selection of outside specialists for panel membership and to establish a working procedure which could lead

to maximum data return and study results.

The aggregate result of the coordination meetings was a Study format and modus operandi, as shown in Figure F-2. This format served as the basic guidelines for the conduct of work at Sagamore, and was the basis of preparation for reports and presentations which summarize the conclusions and results from the Sagamore Conference.

Figure F-2
MEETING FORMAT AND MODUS OPERANDI



II. CONFERENCE MANAGEMENT AND ADMINISTRATION

The Study Group enjoyed exclusive use of the Sagamore Conference Center for the entire week of the meeting. The Conference Center is located in the Central Adirondack Mountains of New York State, eighty miles north of Utica.

The participants were housed in the lodges and cabins located throughout the grounds of the Conference Center. The meetings of the Panels and Steering Committee were held in the various meeting rooms of the main Conference Hall and the outlying lodges. All general sessions, group plenary meetings and final presentations were held in the main Conference Building.

The Main Conference Building served as the on-site administration and staff support area for the meeting. Administrative support consisted of the typing and preparation of reports developed by the panels throughout the Conference. Equipments were available to provide viewgraphs, visual aids and reproductions as required. A message center was located in this building to receive incoming telephone calls directed to the participants.

Each of the meeting rooms were equipped with blackboards, flip charts, adding machines and audio/visual equipments. Additionally, tape recorders were used to record the concluding session and those presentations and discussions deemed vital to summary reporting.

The participants were issued at the time of arrival a Final Program which identified meeting rooms and times for the respective sessions. Name badges were issued, on the basis of a color coding system to identify their panel membership. Each participant was charged a flat rate of $22 per day, which included food and lodging. Attendees were encouraged to dress informally in order to create a shirt-sleeve working environment.

The participants arrived at Sagamore during the early afternoon hours of Monday, 28 August. Buses were used to transport approximately fifty of the attendees from the Syracuse Airport. Other participants traveled by private auto and rental car to the Conference Site. All participants were registered by mid afternoon of the Opening Day.

Following registration and dinner, the attendees convened in the main Conference Hall for the Opening Keynote and General Session. For the next three days, the individual panels met in working sessions to prepare their reports and findings. The Steering Committee interacted with the working panel activities, and met in separate sessions with panel chairmen to review overall progress and to provide advisory inputs. The Schedule of Activities shown in Figure F-3 presents the listing of events and their relative time phasing to the overall meeting. The afternoon and evening hours of Thursday, 31 August, were devoted to corrective actions and preparation of the presentations to the Air Force Materials Laboratory Management. The meeting was adjourned on Friday morning following the panel presentations and the Air Force response.

Figure F-3

SAGAMORE MEETING SCHEDULE

	MONDAY 28 AUG	TUESDAY 29 AUG	WEDNESDAY 30 AUG	THURSDAY 31 AUG	FRIDAY 1 SEPT
MORNING		PANEL MEETINGS (8:30 — 11:30) STEERING COMMITTEE INTERACTION (8:30 — 11:30)			STEERING COMM AND PANEL PRESENTATIONS TO AFML MGMT (8:30 — 12:00)
		LUNCH BREAK (11:30 — 12:30)			ADJOURNMENT
AFTERNOON	PARTICIPANT ARRIVAL STEERING COMMITTEE MEETING (5:00 — 5:30)	STEERING COMMITTEE MTG (12:30 — 1:30) PANEL MEETINGS (12:30 — 5:30)		PANEL BRIEFING PREPARATION & REVIEW (12:30 — 6:00)	
		DINNER BREAK (6:00 — 7:30)			
EVENING	GENERAL SESSION & KEYNOTE (8:00 — 9:00)	STEERING COMMITTEE & PANEL CHAIRMAN MEETING (7:30 — 8:30)		PANEL REPORT PREPARATION (7:30 — 10:00	

III. LIST OF CONFERENCE PARTICIPANTS

STEERING COMMITTEE MEMBERS

Henry A. Johnson, Chairman
Chief, Metals Branch
Manufacturing Technology Division (AFML/LTM)
Wright Patterson AFB, OH 45433

Mr. Marvin Alexander
Director Structures & Design
Convair Aerospace Division
General Dynamics Corporation
P. O. Box 748
Ft. Worth, Texas 76101

Mr. Joseph R. Carter
President
Wyman Gordon Company
Worcester, Mass. 01601

Air Force Materials Laboratory
Materials Support Division (LA)
Attn: Major Tom Ferguson
Wright-Patterson AFB, OH 45433

Mr. Dean K. Hanink
Manager, Engineering Operations
Detroit Diesel Allison Division
General Motors Corporation
P. O. Box 894
Indianapolis, Indiana 46206

Mr. Ed W. Horn/ENJEA
Aeronautical Systems Division
Propulsion & Power Engineering
Wright-Patterson AFB, OH 45433

Mr. Lou Jahnke,
Manager, Materials & Processes
Technology Laboratory
General Electric Company
Aircraft Engine Group
Evendale, Ohio 45215

Mr. Norm Klimmek
Manager Materials & Proc. Laboratory
North American Rockwell Corporation
Los Angeles Division
Los Angeles Intl. Airport
Los Angeles, Calif. 90009

Mr. Walter A. Ledwith
Assist. Chief Engine Design
Pratt & Whitney Aircraft Division
United Aircraft Corporation
West Palm Beach, Florida 33402

Mr. William Miller/ENF
Airframe Engineering
Aeronautical Systems Division
Wright-Patterson AFB, OH 45433

Mr. J. W. Price
President
Reactive Metals, Inc.
Niles, Ohio 44446

Mr. Emil Szabo
Director Production Engineering
Department 350, Bldg 33
McDonnell-Douglas Corporation
P. O. Box 516
St. Louis, Missouri 63166

Air Force Liaison

Mr. Gail E. Eichelman
Technical Manager, Fabrication
Manufacturing Technology Div. (AFML/LTM)
Wright-Patterson AFB, OH 45433

Mr. George M. Glenn
Technical Manager, Processing
Manufacturing Technology Div.
(AFML/LTM)
Wright-Patterson AFB, OH 45433

PRIMARY STRUCTURES PANEL MEMBERS

Mr. Ray Pearson, Chief Engineer
Structure Design
The Boeing Company
P. O. Box 3707
Seattle, Washington 98124

Mr. Roger G. Broadwell,
Mgr. Technical Service and Dev.
Titanium Metals Corporation of America
195 W. Clinton Rd.
West Caldwell, N.J. 07006

Mr. Harvey Buffum
Mgr. Manufacturing R&D
The Boeing Company
Commercial Airplane Group
Seattle, Washington 98124

Mr. Hubert V. Davis
General Weight and Value Department
Lockheed-Georgia Company
Department 72-23, 2457
80 South Cobb Dr.
Marietta, Georgia 30060

Mr. Robert Dayking
Director of Research
Ladish Company
Cudahy, Wisconsin 53110

Mr. Joe D. Van Dyke
Deputy Director,
Structural Engineering
McDonnell-Douglas Corp.
Dept. C1-251, Mail Code 35-41
38 Lakewood Blvd
Long Beach, Calif. 90801

Mr. Norm Taylor,
Director
Product Development, P32-54
The Boeing Company
Vertol Division
P. O. Box 16858
Philadelphia, Pa. 19142

Mr. Al Langlois, Deputy Mgr.
Manufacturing R&D
Northrop Corporation
Aircraft Division
3901 West Broadway
Hawthorne, Calif. 90250

Mr. Norm Taylor, Director
Product Development, P32-54
The Boeing Company
Vertol Division
P. O. Box 16858
Philadelphia, Pa. 19142

Mr. F. Tom Main
Director, Mat'ls & Processes
Grumman Aerospace Corporation
Plant #12
South Oyster Bay Road
Bethpage, LI, NY 11714

Mr. Charles Marshall
Chief Production Design Engr.
McDonnell-Douglas Corporation
Dept. 217
P. O. Box 516
St. Louis, MO 63166

Mr. Peter Brookman, Technical Mgr
Industrial Sales Division
Alcoa Corporation
1501 Alcoa Bldg.
Pittsburgh, Pa. 15219

Mr. W. N. Ottenville, Asst. Dir.
Engineering and Development
Avco Corporation
Materials Engineering
Nashville, Tennessee 37202

III. LIST OF CONFERENCE PARTICIPANTS

STEERING COMMITTEE MEMBERS

Henry A. Johnson, Chairman
Chief, Metals Branch
Manufacturing Technology Division (AFML/LTM)
Wright Patterson AFB, OH 45433

Mr. Marvin Alexander
Director Structures & Design
Convair Aerospace Division
General Dynamics Corporation
P. O. Box 748
Ft. Worth, Texas 76101

Mr. Joseph R. Carter
President
Wyman Gordon Company
Worcester, Mass. 01601

Air Force Materials Laboratory
Materials Support Division (LA)
Attn: Major Tom Ferguson
Wright-Patterson AFB, OH 45433

Mr. Dean K. Hanink
Manager, Engineering Operations
Detroit Diesel Allison Division
General Motors Corporation
P. O. Box 894
Indianapolis, Indiana 46206

Mr. Ed W. Horn/ENJEA
Aeronautical Systems Division
Propulsion & Power Engineering
Wright-Patterson AFB, OH 45433

Mr. Lou Jahnke,
Manager, Materials & Processes
Technology Laboratory
General Electric Company
Aircraft Engine Group
Evendale, Ohio 45215

Mr. Norm Klimmek
Manager Materials & Proc. Laboratory
North American Rockwell Corporation
Los Angeles Division
Los Angeles Intl. Airport
Los Angeles, Calif. 90009

Mr. Walter A. Ledwith
Assist. Chief Engine Design
Pratt & Whitney Aircraft Division
United Aircraft Corporation
West Palm Beach, Florida 33402

Mr. William Miller/ENF
Airframe Engineering
Aeronautical Systems Division
Wright-Patterson AFB, OH 45433

Mr. J. W. Price
President
Reactive Metals, Inc.
Niles, Ohio 44446

Mr. Emil Szabo
Director Production Engineering
Department 350, Bldg 33
McDonnell-Douglas Corporation
P. O. Box 516
St. Louis, Missouri 63166

Air Force Liaison

Mr. Gail E. Eichelman
Technical Manager, Fabrication
Manufacturing Technology Div. (AFML/LTM)
Wright-Patterson AFB, OH 45433

Mr. George M. Glenn
Technical Manager, Processing
Manufacturing Technology Div.
(AFML/LTM)
Wright-Patterson AFB, OH 45433

PRIMARY STRUCTURES PANEL MEMBERS

Mr. Ray Pearson, Chief Engineer
Structure Design
The Boeing Company
P. O. Box 3707
Seattle, Washington 98124

Mr. Roger G. Broadwell,
Mgr. Technical Service and Dev.
Titanium Metals Corporation of America
195 W. Clinton Rd.
West Caldwell, N.J. 07006

Mr. Harvey Buffum
Mgr. Manufacturing R&D
The Boeing Company
Commercial Airplane Group
Seattle, Washington 98124

Mr. Hubert V. Davis
General Weight and Value Department
Lockheed-Georgia Company
Department 72-23, 2457
30 South Cobb Dr.
Marietta, Georgia 30060

Mr. Robert Daykin
Director of Research
Ladish Company
Cudahy, Wisconsin 53110

Mr. Joe G. Van Dyke
Deputy Director,
Structural Engineering
McDonnell-Douglas Corp.
Dept. C1-251, Mail Code 35-41
38 Lakewood Blvd
Long Beach, Calif. 90801

Mr. Al Langlois, Deputy Mgr.
Manufacturing R&D
Northrop Corporation
Aircraft Division
3901 West Broadway
Hawthorne, Calif. 90250

Mr. F. Tom Main
Director, Mat'ls & Processes
Grumman Aerospace Corporation
Plant #12
South Oyster Bay Road
Bethpage, LI, NY 11714

Mr. Charles Marshall
Chief Production Design Engr.
McDonnell-Douglas Corporation
Dept. 217
P. O. Box 516
St. Louis, MO 63166

Mr. Peter Brookman, Technical Mgr.
Industrial Sales Division
Alcoa Corporation
1501 Alcoa Bldg.
Pittsburgh, Pa. 15219

Mr. W. N. Ottenville, Asst. Dir.
Engineering and Development
Avco Corporation
Materials Engineering
Nashville, Tennessee 37202

PRIMARY STRUCTURES PANEL MEMBERS - Continued

Mr. Joe Melill
Materials and Processes
North American Rockwell Corp.
Los Angeles Division
Dept. 056-066, Mail Code SB08
Los Angeles, Calif. 90009

Mr. Robert Roehrs
Senior Group Engineer
McDonnell-Douglas Corporation
Dept. 372, B33
P. O. Box 516
St. Louis, Mo. 63166

Air Force Liaison

Mr. Norman E. Klarquist
Air Force Materials Laboratory/LTM
Wright-Patterson AFB, OH 45433

Mr. Frederick R. Miller
Air Force Materials Laboratory/LTM
Wright-Patterson AFB, OH 45433

SECONDARY STRUCTURES PANEL MEMBERS

Mr. Wm. W. Wood, Chairman
Manager Manufacturing Development
Vought Aeronautics
LTV Aerospace Corporation
P. O. Box 5907
Dallas, Texas 75222

Mr. C. Axtell, Manager
Manufacturing Research
Lockheed-California Company
Lockheed Aircraft Corp.
Dept. 1001, Bldg. 63, Plant A-1
P. O. Box 551
Burbank, California 91503

Mr. R. Baillie, Manager
Manufacturing Producibility
North American Rockwell Corporation
Los Angeles International Airport
Dept. 011, Mail Code AB83
Los Angeles, Calif. 90009

Mr. J. Kiser
A/C Dev. Eng. Specialist
Advanced Stress Dept.
Lockheed Aircraft Corporation
Dept. 72-26, Zone 459
Marietta, Georgia 30060

Mr. R. Lingen, Vice President
Stresskin Products Co.
Div. of Tool Research and Engineering Corp.
3030 South Red Gill Avenue
Santa Ana, CA 92705

Mr. C. Micillo, Manager
Advanced Materials & Process Div.
Advanced Manuf. Development
Grumman Aerospace Corporation
Bethpage, New York 11714

Mr. S. Paterson, Jr.
Supervisor Manufacturing R&D
Or. 6-7310, M/S 40-04
The Boeing Company
Commercial Airplane Group
P. O. Box 3707
Seattle, Washington 98124

Mr. C. R. Ronan, Supervisor
Manufacturing Research
Rohr Corporation
P. O. Box 643
Riverside, CA 92502

Dr. Ivan Baksay,
Quality Control Manager
Zirconium Technology Corporation
P. O. Box 947
Albany, Oregon 97321

Mr. Don Strand
Staff Engineer, Structures Design
The Boeing Company
Commercial Airplane Group
P. O. Box 3707
Seattle, Washington 98124

Air Force Liaison

John R. Williamson
Air Force Materials Laboratory/LTM
Wright-Patterson AFB, OH 45433

William Harris
Air Force Materials Laboratory/LTM
Wright-Patterson AFB, OH 45433

ROTATING ENGINE COMPONENTS PANEL MEMBERS

Mr. Joseph Moore, Chairman
Chief, Materials Laboratories
Pratt & Whitney Aircraft Co.
Florida Research & Development Ct.
Box 2691
West Palm Beach, Florida 33402

Mr. Mel Siegel
Materials Dev. Laboratories
Pratt & Whitney Aircraft Co.
Florida Research & Dev. Ctr.
Box 2691
West Palm Beach, Florida 33402

Mr. Roy Athey
Chief, Materials Dev. Laboratories
Pratt & Whitney Aircraft Co.
Florida Research & Dev. Ctr.
Box 2691
West Palm Beach, Florida 33402

Mr. Richard Barbian
Manager, TF 39 Engineering
General Electric Company
Aircraft Engine Group
Cincinnati, Ohio 45215

Mr. James Coyne
Director of Advanced Materials & Proc.
and Research & Development
Wyman-Gordon Company
Worcester, Mass. 01601

Mr. William Freeman
Vice President, Technical Center
Howmet Corporation
Whitehall, Michigan 49461

Dr. Frank Richmond
Vice President - Tech. Director
Universal Cyclops Specialty Steel Div.
Research and Development Laboratory
Bridgeville, Penna. 15017

Mr. Ken Stalker, Consult. Engr.
General Electric Company
Aircraft Engine Group
Materials and Process Techn. Lab.
Cincinnati, Ohio 45215

Mr. V. A. Vaughn, Sales Mgr.
Teledyne Allvac
Monroe, North Carolina 28110

Mr. J. M. Wentzell
President
Homogenous Metals, Inc.
West Canada Blvd.
Herkimer N. Y. 13350

Air Force Liaison

Mr. J. K. Elbaum
Air Force Materials Laboratory/LTM
Wright Patterson AFB, OH 45433

Mr. L. P. Clark
Air Force Materials Laboratory/LTM
Wright Patterson AFB, OH 45433

Mr. T. Norbut
Air Force Aero Propulsion Laboratory
Wright Patterson AFB, OH 45433

NON-ROTATING ENGINE COMPONENTS PANEL MEMBERS

Mr. Reed E. Yount, Chairman
Manager, Manufacturing Process
Applications Div.
General Electric Company
Aircraft Engine Group
Evendale, Ohio 45215

Mr. N. B. Edenborough
Section Chief NDI Ceramics
Detroit Diesel Allison Division
General Motors Corporation
Mail Stop W-16
P. O. Box 894
Indianapolis, Indiana 42691

Mr. J. Rodin
Sr. Design Engineer
Pratt & Whitney Aircraft Div.
United Aircraft Corporation
400 Main Street
East Hartford, Conn. 06108

Mr. P. E. Hamilton
Chief, Materials Engineering
Materials Engineering Department
Detroit Diesel Allison Division
General Motors Corporation
Mail Stop W-16
P. O. Box 894
Indianpolis, Indiana 42696

Mr. Stan T. Wlodek
Manager, Physical Metallurgy
Stellite Division
Cabot Corporation
1020 W. Park Ave.
Kokomo, Indiana 46901

Dr. Wm. P. Koster
Vice President
Metcut Research Associates, Inc.
3980 Rosslyn Drive
Cincinnati, Ohio 45209

Mr. Bacon Yeung
Manufacturing Process Applications Div
General Electric Company
Aircraft Engine Group
Evendale, Ohio 45215

Mr. Chuck P. Mueller
Vice President
REM Metals Corporation
P. O. Box 829
Albany, Oregon 97321

Mr. R. A. Sprague
Asst. Mgr. Process Development & Eval.
Pratt & Whitney Aircraft Co.
United Aircraft Corp.
400 Main St.
East Hartford, Conn. 06108

Air Force Liaison

Russel L. Kennard
Air Force Materials Laboratory/LTM
Wright-Patterson AFB, OH 45433

Larry P. Clark
Air Force Materials Laboratory/LTM
Wright-Patterson AFB, OH 45433